SEEING THE FOREST FROM THE SKY:

JOINT AIRPOWER THROUGH THE LENS OF COMPLEX SYSTEMS THEORY

BY

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The undersigned certify that this thesis meets masters-level standards of research, argumentation, and expression.

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DISCLAIMER

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ABSTRACT

History describes humankind's struggle to adapt and compete in a dynamic world described by both linear and nonlinear interactions. Despite this, scientific approaches to understanding strategy and war have been described primarily in linear terms and concepts, making both accurate prediction of outcomes and the formulation of effective strategy difficult. Complex systems theories offer more precise conceptual models of the world we operate in, helping us to better identify and balance between multiple competing priorities, risks, and costs. Combined with military theory, complex systems theory can help bridge the gap between prescriptive and descriptive theories of war. These theories also offer Airmen the tools and concepts needed to better understand and explain the multidimensional aspects of airpower, improving their ability to provide the joint force the best tradeoffs between effective and efficient uses of airpower at various levels of scale.

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Introduction

"We can't solve problems by using the same kind of thinking we used when we created them."

Albert Einstein

"It is not often that one gets to witness a scientific revolution in the making, particularly one that will have such a large impact on the world."

Eric D. Beinhocker

When we say that individuals "can't see the forest for the trees," we are not paying them a compliment. Instead, we are recognizing a defect in cognition, a failure to discern a broader pattern of meaning that is more important than the sum of the details. Taken literally, the closer one focuses upon examining individual trees in a forest, the more difficult it becomes to tell if one is even in a forest at all. When one flies high above that same tree, it becomes lost in the broader pattern of color, shape, and wind driven motion that we describe as a forest. Both perspectives tell us something about the forest, but neither is sufficient to understand what a forest is or what it does as a whole. If we could transition back and forth between both the micro and macro perspectives, we might come up with a better overall description of the forest and what goes on there, but we would still be lacking crucial information about what a forest is if we only looked during one hour, one day, or one season of the year. In fact, if we could observe the forest long enough, we would learn not only that forests change, we would be able to *see the forest moving,* adapting its boundaries and composition to simultaneous stimuli such as wind, water, shifting soil, insects, animals,

and the influence of people. For thousands of years, most fields of human inquiry have concentrated mainly on the trees rather than the forest. With complex systems theories, this is finally starting to change.

It's remarkable that in several millennia of scientific and intellectual inquiry, science has focused primarily on understanding the individual parts of our world, rather than on discerning the broader patterns and collective phenomena that give them meaning. It is only very recently that studies of complex systems have sought to remedy this deficiency, and the results have been electrifying.

Why Complexity?

Throughout history, the story of science has been one of translating broad, metaphorical abstracts of the world into more precise models and descriptions that better describe the world as it really is. Using this knowledge, we make predictions about cause and effect, and use those predictions to design the strategies, plans and tools that help us both shape and adapt to our ever changing world. Historically, science has tried to design better models by breaking up the world into smaller pieces, or systems, that are both accurate and easier to understand.[1] Once the pieces are understood, these separately derived understandings are recombined to make conclusions about the whole. Western science, from the early contributions of Aristotle to the scientific revolution of Newton's theories, has been largely based on this method of linear reduction, called *analysis*. Ironically, the more analytic sciences progressed, the more their shortcomings in explaining a dynamic world became apparent.

As analytic studies typically favor looking at systems in equilibrium and in individual pieces, they usually fail to adequately

[1] Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009), 16-19.

describe phenomena than can only be observed and understood when the pieces are dynamically interacting with each other. For example, by looking at a car, a house, a cow, a thousand bushels of corn, several tons of dirt, and overlapping air masses of hot and cold air, we can learn something about the system that includes them all. But unless we can observe them violently circulating around each other through the air at over 200 miles per hour, we don't know that the system we're looking at is actually a tornado. Until recent times, it was very difficult to approximate nonlinear interactions in complex systems like a tornado, in which the system could not be approximated by adding up the sum of the parts. Beginning in the 1970s, systems theory and modern computing came together to create new ways of studying and modeling the emergent qualities of dynamically interacting systems, and the field of study eventually known as *complex systems theory* was born.[2]

Complexity in Warfare

Despite the fact that war has been a constant throughout human history, one might draw the conclusion from recent military writings that understanding it is becoming more and more difficult. Choose any recent assessment of the operational environment, and one word is increasingly being used to describe it (italics are the authors):

"A *Complex* Environment: The United States faces a *complex* and uncertain security landscape in which the pace of change continues to accelerate."[3]

- 2010 *Quadrennial Defense Review*

[2] Eric D. Beinhocker, *The Origin of Wealth: The Radical Remaking of Economics and What it Means for Business and Society* (Boston: Harvard Business School Press, 2007), 18.

[3] *Quadrennial Defense Review Report*, by Robert Gates, Secretary of Defense (Washington DC: Government Printing Office, 2010), iiii.

"The United States faces a *complex* and rapidly shifting international security landscape."[4]

- 2009 *National Intelligence Strategy*

"*Complex* environment: Globalization, the information revolution, non-traditional adversaries, and our changing military capabilities have significantly changed today's security environment." [5]

- Joint Operations: Insights and Best Practices

"Regardless of the specific form one believes the future world will take, it is clear that the international system of the new millennium is evolving toward, or returning to, a more *complex* environment."[6]

- CNAS *Contested Commons* Jan 2010

The use of the word *complex* in each case, rather than *complicated*, is deliberate, indicating intentional allusions to the basic concepts of complex systems theory. Western military communities are increasingly adopting a complex systems mindset in thinking about war and warfare, recognizing that it more accurately describes the actual nature of the

[4] *National Intelligence Estimate 2009*, by Dennis Blair, Director of National Intelligence (Washington DC: Govenment Printing Office, 2009), 1.

[5] Joint Warfighting Center, *Joint Operations: Insights and Best Practices* (Washington DC: Government Printing Press, 2008), 1-2.

[6] Abraham M. Denmark, Dr. James Mulvenon,Frank Hoffman, Lt Col Kelly Martin (USAF), Oliver Fritz, Eric Sterner,Dr. Greg Rattray, Chris Evans, Jason Healey, Robert D. Kaplan, *Contested Commons:The Future of American Power in a Multipolar World*, ed. Abraham M. Denmark and Dr. James Mulvenon (Washington DC: Center for a New American Security, 2010), 19.

operational environment than older, linear based concepts. As military commanders and their staffs are continually forced to deal with a multitude of simultaneous challenges in various domains, they are increasingly drawing from the rich intellectual concepts and language of complexity theory to describe and understand them.

In embracing complexity, western militaries have joined in an intellectual exploration that originally began in the scientific community, but has since expanded to include other fields such as medicine, social science, political science, and business management. Ironically, the rise of complex systems theory can be described in terms of *emergence*, one of its key concepts. Various professional communities randomly interacting with — and reacting to — each other have led to a "bottom up" acceptance of the complex systems theory's basic descriptions and terms, with no central directors coordinating outcomes.

To understand complexity, one must necessarily study systems and networks. Systems theory predates the body of work currently described as complexity theory, and was initially developed to understand linear systems under the old analytical methods. Despite this, the language and concepts of systems theory have lent themselves well to complexity studies, which seek to explain how dynamically interacting systems form emergent properties that are evident only while the interaction is taking place. This blending of complexity theory with these more mature intellectual traditions of general system theory is increasingly referred to collectively as the *science of complex systems*, blending these complimentary but formerly distinct fields of study.[7] As the science of complex systems continues to emerge and gain acceptance, other fields of study have increasingly found common value

[7] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 24.

in like concepts applied to their individual studies, whether one is referring to biological systems, communications systems, economic markets, social networks, or nations in competition.

It is logical that military thinkers should follow developments in various fields of study; if there is any field of study that calls for a holistic understanding of the myriad aspects of the human condition, it is the study of war and warfare. The US military's recent embrace of complex systems theory has been driven more by necessity than preference. The rapid toppling of the Afghan Taliban and Iraqi regimes in 2001 and 2003 respectively were originally portrayed as stunning military successes by those who had engineered these initial tactical successes. Both efforts quickly proved to be hollow victories, as failures to understand extreme complexity of the situation in both countries led to policy decisions and military follow on actions that fueled lethal insurgences in both countries, negating the benefits of the earlier tactical successes. Both operations demonstrate the dangers of instituting policies by force without having sufficient understanding of what the cascading second and third order effects of those actions might be in complex environments. Spurred largely by the failure of traditional operational design concepts to stem increasing violence and mounting casualties, Western militaries have increasingly looked to the conceptual tools of complex systems theory to help them better understand operating environments, define problems, and design new strategies in an effort to bring stability to our current conflicts.[8]

As complex systems theories have informed modern military training, education, doctrine, planning, and command and control, they have also shed new light on the reasons why some classic military

[8] *FM 5-0: The Operations Process,* by General Martin E. Dempsey, US Army, Commanding General, US Army Training and Doctrine Command (Washington DC: Government Printing Office, 2010), 3-7.

theories have stood the test of time despite vast changes technology and scientific understanding since the time they were written. From Sun Tzu, through Clausewitz, and even in recent updates to classic counterinsurgency doctrine, principles of complex systems theory can both show why proven theories endure, and why new innovations in operational art might hope to succeed where other attempts have failed.

Various military theorists have attempted to discern general principles and descriptions that could help military leaders and strategists better understand war, with varying degrees of success. Despite this, there are relatively few unifying concepts that might someday serve as a general theory of war. While complex systems theories may not yet offer a bridge between prescriptive and descriptive military strategies, they do help to further explain the best military theories of the past, and offer promising potential for the development of future ones that better describe the cognitive, moral, and physical domains in which every war is fought. While an understanding of complexity theory may someday help us explain how warfare has changed, its greatest contribution to military theory may be simply to give us more nuanced view of how it has stayed the same.

With their heavy dependence on technology, communications, physical infrastructure, maintenance, and domains inhospitable to human habitation, military air operations have arguably always been complex affairs. Despite this, there have been relatively few attempts to apply the conceptual concepts of complexity theory to find useful applications for the planning, control, and execution of air and space operations. This study will show how a basic understanding of the concepts of complex systems will help Airmen better understand their operating environments, define their problems, and collaborate with joint partners to design solutions for achieving the political aims that military strategy necessarily serves.

Study Methodology

This study begins with an overview of the most important concepts from complexity theory, including a brief review of the traditional analytical sciences that they evolved from. It will examine several definitions of complexity, describe how complex systems interact, and introduce key concepts like emergence, complex adaptive systems, and adaptation. It will discuss the differences between being complicated and complex, and discern the difference between levels of complexity and levels of scale. This chapter will show how complexity theory focuses on dynamic flows and interactions between individual components of systems rather than the components themselves, and will show how even unintelligent complex systems can achieve higher levels of organization with no intelligent central direction — seemingly flying in the face of concepts like entropy and chaos.

Second, this study reviews systems and network theories, which describe both the linear and nonlinear aspects of systems in general. Systems and network theories provide powerful insights into how the specific characteristics of those components allow them to become part of systems that exhibit complex behaviors. System theory predates complexity theory by several decades, but the former has been invaluable in describing the insights of the latter. Elements of both have been blended into the current studies of complex systems theory.

Third, this study will demonstrate how the combined insights of both complexity and systems theories can be practically applied to real world situations. Moving beyond purely describing complex systems, one can formulate some prescriptive theories that allow one to better cope with, and at times even influence inherently unpredictable complex systems to increase the probability of producing favorable outcomes.

Fourth, the study will review how Western militaries have either subconsciously or intentionally incorporated complex systems theory

insights into their theories, operating concepts, training, doctrine, and educational processes. Throughout history, military theorists have advocated fundamental theories for war and warfare that can be further clarified, and perhaps even improved, using the concepts of complex systems theory. In more recent times, conscious efforts to embrace the emerging new sciences have often imperfectly captured these concepts, leading to real advances in some areas, and significant stumbles in others. Looking at military theory in the light of complex systems theory will help us better understand why the timeless principles are indeed timeless, and also allow us to recognize where we can improve on and build from past attempts to grapple with the true complexity of the battlefield.

Finally, this paper will propose how concepts from complex systems theory can improve the organization, planning, and execution of air and space operations in the context of joint, combined, and interagency operations. Air operations have always been complex, nonlinear affairs; airpower's inherent capacity for adaptation has arguably made superior airpower a prerequisite for successful large scale military operations, and a vital enabler for nearly all military operations at any level of scale.[9] Despite this, the tools and concepts by which we think about, describe, and evaluate airpower's effectiveness remain decidedly simplistic and linear, and leave modern Airmen ill-equipped to describe, let alone harness, the true capabilities of airpower. When joint airpower is viewed through the lenses of complex systems theory, we can begin to see the true potential of liaison elements like the Air Component Coordination Element (ACCE), which serves as a highly connected hub between the networks of the joint force commander's staff and functional

[9] G. Scott Gorman, "Seeking Clocks in the Clouds: Nonlinearity and American Precision Airpower" (PhD diss., Johns Hopkins University, Baltimore, MD), 2006.

components. Executed properly, the ACCE can help the joint force tap into the creative variety inherent in the joint force that successful adaptation to emerging, unanticipated contingencies. With the graphical tools that enabled the discovery of complex systems theory, we can see the multidimensional aspects of airpower employment closer to the way they are in reality, and create better decision support tools for planning, executing, and assessing the effectiveness of air operations. Finally, if we better comprehend the unpredictable nature of the operational environment, and use the technological tools that are now or will soon be available to us, we can devise operational methods that harness the emergent, random, and unpredictable aspects of the operational execution to our own positive advantage, even when no one is consciously directing the effort.

Caveats

A complete review of all of the nuances of complex systems theory is impossible in a treatment as short as this one, and in truth there is no single authority to define which concepts should or should not be included under its wide umbrella. Due to the rapid and relatively recent merger of complexity and systems theories, there is no universally accepted division of concepts that belong exclusively to either one or the other body of thought. The separation of concepts in chapters one and two are the author's, with distinctions based on the lineage of the concepts and their applicability to dynamic and holistic systems respectively.

Rather than to try and represent the entire breadth of complexity and systems theories, this study will focus on unifying concepts that have driven the merger of the two types of thinking, and also focus on the specific parts of complex systems theory most relevant to achieving a better understanding of how airpower can be integrated into joint airpower applications. Additionally, this study focuses on qualitative

rather than quantitative applications of the theories, with the intention of exposing the widest possible audience of readers to the usefulness of complex systems theory to military thinkers. This study specifically seeks to address Airmen, with the assumption that the term describes an "airminded" individual regardless of national affiliation, service affiliation, or status as an aircrew member.

Chapter 1

Complexity Theory

Air. Earth. Water. Fire. Most of us recognize these as the classical divisions of the Earth's basic elements, even if we're hazy on the concept's origin. To modern high school students confronted with the modern periodic table of the elements, the ancient Greek formulation would likely be most welcome compared to the fractured checkerboard of 118 squares confronting them in their exams. Yet years later, that same student, now a scientist and engineer, may find even the more complicated table of elements insufficient. Looking back at Aristotle's four element formulation, the person who adds the 119^{th} square to the periodic table might wonder "Did they really think that the world was that simple way back then?" Ironically, Aristotle may have thought the same while looking back at his fellow Greek Thales of Miletus, who nearly 200 years earlier had proposed that all natural substances were modifications of the single element water.

Did the elements themselves change between the ages of Thales and Aristotle, or between Aristotle's time and today? Of course not. What did change was our ability to conceptualize the world's inherent complexity, after over two millennia of reflection, experimentation, and intellectual innovation. This paper proposes that modern complexity and systems theories have the potential to turn our ways of thinking about strategy, the operational environment, and joint warfighting on their heads in the same way that that Aristotle's ideas once did to Thales' and the periodic table did to Aristotle's.

Perhaps one of the best ways to demonstrate how complexity theory works is to look at how the theory itself emerged. Not developed through a conscious or deliberate effort by any single actor or entity, the body of thought currently described as complexity theory gradually gelled from the combined contributions of various interacting academic and scientific communities. Though members from the different communities were seeking advances pertaining to their own specialties and interests, the more those members shared their insights with the other communities, the more it became apparent that common principles were at play in nearly all of the disciplines. Whether one studies war, molecular biology, the interaction of ants and slime molds, international politics, or the way cities grow and develop, it becomes evident that one cannot truly understand a system by simply examining its parts, nor can one understand the parts without looking at their context and purpose within their environment.

Early Attempts to Explain a Complex World

Scientific investigation has attempted to understand the incomprehensible whole of the universe by breaking it into more easily understood pieces. As early as the sixth century BCE, when Thales described the world as a slab of land floating on an infinite sea of water, scientific inquiry has tried to break up the complexity of the universe into distinct, separate subcomponents that could be repeatedly described and predicted with accuracy.[1] As scientific inquiry progressed, scientists like Aristotle, Galileo, Copernicus, Kepler, and Newton all sought to use this concept — reductionism — to explore what they understood to be a "Clockwork Universe".[2] This term, originally attributed to LaPlace,

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[1] Adam Hart - Davis, ed., *Science: The Definitive Visual Guide* (New York: DK, 2009), 22.

[2] Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009), 16-19.

describes a worldview which hypothesizes that the world could be understood in total if the interactions of the parts could be described and predicted, using the languages of science and mathematics to finally decode the underlying physical laws of the universe[3] Thus, most of the most significant tools of scientific inquiry for thousands of years, from simple arithmetic to differential calculus, rely on the principle of linearity, which says roughly that the total can be understood as the sum of its parts.[4]

The Analytic Method

For thousands of years, the analytical approach initiated by Aristotle served as the most pervasive foundation for scientific inquiry. Preserved from antiquity through the Dark Ages by a continuous chain of Western and Eastern translators, the Greek analytic method eventually became the fundamental approach of modern science. As defined by modern systems theorist Jamshid Gharajedaghi,

> Analysis is a three-step thought process. First, it takes apart that which it seeks to understand. Then it attempts to explain the behavior of the parts taken separately. Finally, it tries to aggregate understanding of the parts into an explanation of the whole. [5]

The tools of analytic thought, from simple arithmetic to differential calculus, assume that the world can be described in linear terms, meaning that "… we can get a value for the whole by adding up the values of its parts. More carefully, a function is linear if the value of the function, for any set of values assigned to its arguments, it simply a

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[3] John Gribbin, *Deep Simplicity: Bringing Order to Chaos and Complexity* (New York: Random House, 2004), 17.

[4] John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (Cambridge, MA: Perseus Books, 1995), 15.

[5] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 15-16.

weighted sum of those values."[6] Linear sciences have been invaluable to developing most of the technological innovations that we often take for granted to day, informing everything from the basic application of a lever in a child's see-saw, to the complicated calculations needed to safely launch and recover a space shuttle and its astronauts.

It was not until the twentieth century that two major discoveries indicated that it would not someday be possible to predict actions in the universe with mathematical precision. In 1927, Werner Heisenberg's "uncertainty principle" used quantum mechanics to show that because one could not measure both the location and the momentum of a subatomic particle, a precise prediction of its future position was impossible.[7] The second discovery was made by Henri Poincaire, who invented a new branch of linear mathematics called algebraic topology in order to study the motion of three bodies acting upon each other, advancing on Newton's laws which only described the motion of two bodies relative to each other.[8] Poincaire found that even the slightest differences in the initial conditions of the system could produce vast differences in the future motion of the system, making long term predictions of the future state of even simple three body systems practically impossible, even with all of the laws of linear mechanics holding true. It was this hypothesis that computer models would later prove to be valid, providing the basis for modern chaos theory.

With the insights of Heisenberg and Poincaire, it became clear that the "Clockwork" universe model could only explain parts of the universe, not the whole. Admittedly, many system interactions can often be

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[6] Holland, 15.

[7] Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009), 20.

[8] Mitchell, 21-22.

predicted with adequate reliability in the short term, allowing imperfect linear approximations of nonlinear processes to support scientific advances for thousands of years. But advances in measuring instruments and computer simulations in the last three decades have yielded new insights into the nature of nonlinear interactions, and have provided new clues as to how broader patterns of organization can emerge even from seemingly random interactions of relatively unintelligent agents within an adaptive system.

Why Complexity Theory?

Although science has been able to describe much of the universe using linear concepts, in the last thirty years it has became increasingly apparent that classical science was not up to the task unassisted. T. Irene Sanders explains this deficiency in her book *Strategic Thinking and the New Science*,

> The natural world is filled with a variety of rich textures, shapes, and patterns – the rough bark on a tree, the long graceful limbs of a fern, stepping-stones across a stream. Yet, the richness of the real world could only be appreciated in the abstract by classical science. Scientists could identify the elements in a molecule of water, H_2O, but not the dynamics at work in a waterfall. New approaches were needed for exploring mysteries that they saw all around them– variations in cloud patterns, fluctuations in weather and wildlife populations, and changes in the rate and flow in mountain streams…Those who would later be recognized as chaos pioneers began to probe these questions, even though they were warned against this by their colleagues…Physics, biology, mathematics, astronomy, meteorology-all provided paths, first into *chaos*, and then into *complexity*.[9]

As the tools provided by the linear sciences improved scientists abilities to look at the parts of the world separately, those same tools, especially modern computers, started to give them new insights into the

[9] T. Irene Sanders, *Strategic Thinking and the New Science* (New York: The Free Press, 1998), 63, 65.

interactions of the parts as well. As scientists from different fields traded notes on what they were seeing, it became increasingly apparent that many of the same nonlinear principles were at work in many formerly disparate fields of study. Modern exploration of these common phenomena began in the Santa Fe Institute, whose founding in 1984 and initial development is described in M. Mitchell Waldrop's 1992 book *Complexity: The Emerging Science at the Edge of Chaos.* The Santa Fe Institute's interdisciplinary effort to understand nonlinear phenomena developed into a field of study known collectively as complexity theory.[10]

What is Complexity?

While there is no universally accepted definition of complexity, all of the contending definitions recognize that complex systems are dynamic ones that exhibit collective properties at the macro level that cannot be anticipated by understanding its parts separately at the micro level. As described by Yaneer Bar -Yam, the President of the New England Complex Studies Institute (NECSI),

> "Complex Systems" is a new approach to science, which studies how relationships between parts give rise to the collective behaviors of a system and how the system forms relationships with its environment…Studying complex systems cuts across all disciplines of science, as well as engineering, management, and medicine. It is also relevant to the humanities; art, history, and literature. It focuses on certain questions about relationships and how they make collections of parts into wholes. These questions are relevant to all systems that we care about.[11]

While there is also no commonly defined measure of complexity within a system, there are ways to characterize relative complexity

[10] M. Mitchell Waldrop, *Complexity: The Emerging Science at the Edge of Chaos* (New York: Simon and Schuster, 1992).

[11] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 24.

between various systems. As described by Dietrich Dörner in *The Logic of Failure*,

> *Complexity* is the label we give to the existence of many interdependent variables in a given system. The more variables and the greater their independence, the greater the system's complexity…The links between the variables oblige us to attend to a great many features simultaneously, and that, concomitantly, makes it impossible for us to undertake only one action in a complex system.[12]

One of the keys to understanding the nature of complexity is the difficulty one has in predicting specific outcomes from a single action in a complex system. The more highly connected the variables of a system are, and the more sensitive various parts of the system are to perturbations in other parts, the more difficult it is to anticipate the probability and preponderance of good vs. bad outcomes from a single act, let alone multiple acts within the system. This is why Bar-Yam describes a complex environment as "one that demands picking the right choice in order to succeed. If there are many possibilities that are wrong, and only a few that are right, we have to be able to choose the right ones in order to succeed."[13] Thus, our ability to operate in complex environments is not easily predictable, and single actions often create multiple outcomes that we didn't intend.

Sources of Complexity

The amount of complexity we experience depends not only on the diversity of possible outcomes from a single act, but also in our cognitive ability to account for the numerous variables in the system and their interactions. Take for example the modern process of choosing a movie,

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[12] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex situations* (New York: Basic Books, 1996), 38.

[13] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 67.

ordering tickets, and driving to the theater—a typical Friday night for many American teenagers. A single telephone can easily be used by average sixteen year olds to invite multiple friends to see the movie via text messages, buy tickets with their credit cards, check movie reviews, update their Facebook statuses, and play music in the car as they drive to the theater. Our teens in this example take for granted things like rechargeable batteries, 3G networks, synchronized traffic signals, the serviceability of roads between their houses and the theater. It's assumed that other drivers understand and will follow the rules of the road, that pressing buttons on the phone will activate the economic system that allows us to by movie tickets with money we haven't earned yet, and that ultimately that money which exists only as ones and zeros will translate into another teen providing a ticket at the will call window. At an even more basic level, teens take it for granted that it is their friends they are talking to on the phone, not some impersonating charlatan or a demon from another world.

Even though this maze of interconnected variables would likely paralyze us if we tried to understand them in pieces, trips to the movies do not, and are usually enjoyable experiences that actually decrease our stress. Why? Because modern moviegoers have developed the cognitive tools to handle the associations of the multiple variables involved with going to the movies. We are able to adapt to the complexity of the modern world because we have made technological advances with iterative steps and experimentation, and made those advances part of the filters with which we see the world itself.

Disorganized Complexity

While we can reduce the relative amount of complexity we perceive by finding better ways to conceptualize the complex interactions, the number of variables interacting with each other simultaneously can still overpower our ability to process and adapt to them. This can be simply

expressed in the different ways one might use a can of tennis balls: while most tennis players can reasonably cope with the complexity of hitting each of those tennis balls one at a time in a game of tennis, most would probably not be able to cope with the complexity of returning multiple serves all at once, or even juggling all of them in the air at once. In short, our perception of complexity is not only increased by the number of parts interacting, but also by the degree and nature of dynamic change.

Organized Complexity

Now imagine if the tennis balls in our previous example not only bounced off of each other according to the laws of ballistics, but could actually react to one another and the tennis players, changing their trajectory through their own volition with small blasts of air from an internally mounted system of air jets. This would make prediction of their microbehaviors almost impossible, and create yet another level of complexity above the one we experienced when we were trying to keep track of all of them following the law of gravity. However, if we had enough tennis balls reacting to one another, we might notice a pattern of flows that emerges over time and distance, not unlike the swarm behavior of a disturbed hive of bees. This type of complexity, brought about by purposeful reactions of agents to other agents and forming higher level patterns of complexity in the aggregate, is referred to as organized complexity, as the complexity results from deliberate reactions to specific stimuli in the environment.[14]

Emergence

If there is one unifying idea common to the various applications of complex systems, it is that systems can organize from the bottom up as well as from the top down. Contrary to the tendency towards disorder

[14] Steven Johnson, *Emergence* (New York: Scribner, 2001), 48.

that one would expect according to the principle of entropy expressed in Newton's Second Law of Thermodynamics, complex systems often reach higher levels of organization, even when no one is consciously directing the individual pieces of the system to seek them.[15] Whether one studies the workings of the human immune system, the formation of fractals, or the self organization of economies, there is a common characteristic of all complex systems: their capacity to adapt and evolve in response to their surroundings. As Eric D. Beinhocker, a Senior Fellow at the McKinsey Global Institute describes it,

> We are accustomed to thinking of evolution in a biological context, but modern evolutionary theory views evolution as something much more general. Evolution is an algorithm; it is an all purpose formula for innovation, a formula that, through its special brand of trial and error, creates new designs and solves difficult problems…Modern evolutionary theorists believe that, like gravity, evolution is a universal phenomenon, meaning that no matter whether the algorithm is running in a substrate of biological DNA, a computer program, the economy, or in the substrate of an alien biology on a distant planet, evolution will follow certain general laws of behavior.[16]

Thus, complexity theories propose that there are common principles that can be used to describe and understand the processes that drive evolution in all adaptive systems, whether they are considered living or non-living.

Complexity is not just about our ability to account for the number and speed of interactions between multiple variables; it is also about our ability to detect the changing nature of those interactions considered in the aggregate. There is a quality of complex systems that makes

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[15] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 32.

[16] Eric D. Beinhocker, *The Origin of Wealth: The Radical Remaking of Economics and What it Means for Business and Society* (Boston: Harvard Business School Press, 2007), 12-13.

prediction difficult even if one only has to deal with a small number of interconnected variables. Unlike linear systems, complex systems do not respond consistently or proportionally to stimuli from the environment. The interactions of different parts of the system may be governed by a few simple rules, yet the results of these interactions may be difficult or impossible to predict on a micro scale. However, when viewed in the macro scale, one may detect more predictable overall patterns in the collective manifestation of the interactions. In fact, most emergent qualities of complex systems *only* exist while the interactions are taking place, and can only be detected and understood in the context of the whole, as in our previous example of the tornado. These tendencies of complex systems to self organize and form macro patterns of behavior are described by the concept of *emergence.*

> *Emergence* refers to the relationship between the details of the system and the larger view. Emergence does not emphasize the primary importance of the details or the larger view, it is concerned with the relationship between the two. Specifically, emergence seeks to discover: Which details are important for the larger view, and which are not? How do collective properties arise from the properties and the parts? How does behavior at a larger scale of the system arise from the detailed structure, behavior, and relationships on a finer scale?[17]

Thus, emergence recognizes that there are some properties that can only be understood by looking at the aggregate of various independent interactions within a system, not by simply looking at the sum of the parts. This idea can be expressed in fractal patterns of nature such as a tiger's stripes, the combination of harmonies in music, a crowd at a football game doing the wave, or even human consciousness itself. Emergence is both a quality and activity that separates a simple system from an evolving one; it is practically impossible to describe either in

[17] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 27.

linear terms. It is this nonlinearity, and traditional science's inability to account for it, that has led scientists to build new theories based around the concept of complex adaptive systems.

Complex Adaptive Systems

If emergence is a distinguishing characteristic of nonlinear systems, what then are the drivers behind it? How does one describe "a world where many players are all adapting to each other and where the emerging future is extremely hard to predict?"[18] The answer originally proposed at the Santa Fe Institute, which has since been accepted by most complex systems theorists, is to describe both the world, and the smaller systems that comprise it, as *complex adaptive systems.*[19]

Complex adaptive systems are "open nonlinear evolutionary systems, such as the rain forest, that are constantly processing and incorporating new information…Instead of settling into a predictable or steady state like motion of a pendulum, or ultimately dissipating like a hurricane or tornado, these types of systems adapt to change…"[20] While complex adaptive systems are not predictable in the short term due to their ever changing nature, their process of change and adaptation itself is usually driven by basic sets of rules. These rules influence the interactions of less complex lower level parts of the system to exhibit complex behaviors at a higher level, as in the example of the formation of ant nests and termite colonies. [21]

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[18] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), xi.

[19] John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (Cambridge: Perseus Books, 1995), 4.

[20] T. Irene Sanders, *Strategic Thinking and the New Science* (New York: The Free Press, 1998), 63, 69.

[21] Holland, 11.

Feedback

The key to understanding complex adaptive systems, and nonlinear behavior in general, is to understand the role of feedback in evolutionary processes.

> A complex adaptive system is open to flows of energy, matter and information, which flow through networks of both positive and negative feedback. Feedback is a fundamental concept because it marks the difference between linear and non-linear systems. Whereas outputs are always proportional to inputs in linear systems, non-linear systems magnify some inputs (positive feedback) and counteract others (negative feedback). Because feedback creates interdependence, it is a source of complexity. Feedback is also the underlying cause of emergence, self-organisation and attractors.[22]

Even if one cannot hope to completely predict or control the evolution of complex adaptive systems, we might seek to "harness" the emergent properties of a system by planning ahead and allowing for them, or in some cases, even cultivating or mitigating the formation of emergent situations to one's advantage.[23] To do this, one must understand how feedback drives the common processes of variation, adaptation, and selection that drive evolution in complex adaptive systems.[24]

Variation

When we find ourselves confronted with unpredictable situations that may call for very different tools and skill sets to cope with them, we can take two basic approaches: we can place a bet on what kind of

[22] Alex Ryan, "The Foundation for an Adaptive Approach: Insights from the Sciences of Complex Systems," *Australian Army Journal* VI (Summer 2009): 72.

[23] Steven Johnson, *Emergence* (New York: Scribner, 2001), 66-67.

[24] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), xv.

situation we'll be most likely to confront and configure for that likelihood at the expense of others, or we can try to be ready for a number of different possibilities.. Taking the second approach leaves us with the capability to adapt a range of eventualities, but unready to cope instantly with any one of them. Of course, the ideal competitor would have the capability to deal with any and all contingencies. On the individual level in the real world, tradeoffs must always be made, like having to choose between stability and maneuverability in the design of an aircraft, or a football team having to decide between drafting a quarterback or a linebacker in the first round. In the larger view, the more different contingencies one is equipped to deal with, the more successful the system will be in adapting to the emerging situation. In the example of building a football team, the more different kinds of players you have skilled in different areas, the better your overall chances will be when competing against random opponents and their varying strategies. This is especially important when your system is competing with other systems who are consciously adapting to yours. This diversity of coping mechanisms is described in complex systems theory as variation, and serves as the "raw material for adaptation", as well as the central requirement for successful evolution.[25] Whether one is talking about the body's white blood cells that seek out previously unknown pathogens, or a corporation looking for new ways to be competitive in a tight market, the right balance of variation to uniformity is crucial, for without variation, "an increasingly monolithic culture produces an ever-decreasing set of alternatives and a narrow path to victory."[26]

[25] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), 32.

[26] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 6.

Adaptation

Complex Adaptive Systems, whether consciously thinking or not, all have the ability to sense and interpret feedback from their environment, use the coping tools that their variety provides them, and then either adapt successfully to the new conditions or cease to be. This sensing and reaction may be driven by simple chemical reactions, as it is in the case of biological processes and formations of slime molds, but it can also be driven by a high order combination of cognitive and physical activities evidenced by elite athletes in competition. No matter what level of cognition the reacting agent has or doesn't have, or whether it is an individual agent or a collective group, the general requirements for adaptation are the same. The adaptive agent must have the capacity to gain and sustain environmental awareness of the system, it must have a notion of fitness for that environment, it must have the capacity to make changes, and it must have the capacity to retain and encode useful information that improves success.[27] It is this capacity to change not only behavior, but also composition, in ways that optimize success in changing environments that define successful complex adaptive systems.[28]

Selection

If variety provides the building blocks for adaptation, it is selection which determines how a living system adapts to the changes detected in the environment. Selection, or selective retention, is what variants are inhibited (negative feedback) and which ones are reinforced (positive feedback) with a bias towards retaining variants that its notion of fitness

[27] Lieutenant Colonel Mick Ryan, "Measuring Success and Failure in an Adaptive Army," *Australian Army Journal* VI, no. 3 (Summer 2009): 23.

[28] Mick Ryan, 23.

perceives to be most contributory to future success.[29] This process of selection can be facilitated in several different ways. It can be determined by default if an agent has no significant threats to its survival, meaning that the system is inherently fit to survive in the environment in which it finds itself. This is the premise behind Darwin's Theory of natural selection.[30] Selection can also be facilitated by a successful adaptation to otherwise disadvantageous aspects of the environment, as is the case when a mutation gives the agent an advantage against other competitors or environmental factors. Selection can also be the result of deliberate choices by sentinent beings to emphasize one variant over another between two options that are both otherwise compatible with survival within the system. Regardless of how the selection is made, it remains the key to successful adaptation and survival in a complex system.

Variation, adaptation, and selection are the basic components to any action reaction cycle, regardless of its level of complexity or field of interest. According to economist Eric D. Beinhocker,

> Evolution can perform its tricks not just as a substrate of DNA, but in any system that has the right information-processing and information-storage characteristics. In short, evolution's simple recipe of "differentiate, select, and amplify" is a type of computer program-a program for creating novelty, knowledge, and growth. Because evolution is a form of information processing, it can do its order-creating work in realms ranging from computer software to the mind, to human culture, and to the economy. [31]

[29] Alex Ryan, "The Foundation for an Adaptive Approach: Insights from the Sciences of Complex Systems," *Australian Army Journal* VI (Summer 2009): 81.

[30] Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009), 78-79.

[31] Eric D. Beinhocker, *The Origin of Wealth: The Radical Remaking of Economics and What it Means for Business and Society* (Boston: Harvard Business School Press, 2007), 12.

Understanding that this algorithm of evolution applies to both sentient and non-sentient agents and organisms is the key to transferring the concepts of complex systems theory to multiple applications in the real world, and making intellectual connections between discoveries and insights from various disciplines of study that might also apply to yours.

Tagging

In the cases of either conscious or unconscious selection, there must be something that triggers the choice. Complex adaptive systems have the ability to both sense and react to their environments because they have an ability to compare what they sense in the external environment, and then use selection to react in ways that enable survival in that larger system. The stimuli that trigger selection are called *tags*. Tags are descriptive elements that break up symmetry, allowing agents in a complex adaptive system to interact selectively, form aggregates, and establish borders.[32]. Tags can be physical properties, such as the physical components of antigens that cause antibodies in the human body to trigger the auto-immune system. In the case of the collective behaviors of ants, chemical trails left by ants serve as the tags that cause other ants to change their behavior, unconsciously creating communal patterns of activity. Tags can be deliberately chosen, as they are in the example of fans of a particular sports team flocking to a bar decorated in their team's colors for game day. Whether they are intentionally chosen, or preprogrammed into the DNA of an unconscious biological agent, tags serve as the "pacemaker" for environmental sensing and selection, and are thus critical to adaptation and the forming of meta-agents within a

[32] John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (Cambridge: Perseus Books, 1995), 13-14.

complex adaptive system.[33] Without tagging, memory storage, learning and evolution cannot occur.

Meta-Agents

If individual interactions of the agents within a system can create higher levels of complexity through individual adaptation, so too can larger groups of agents acting together create higher complexity behaviors in the aggregate, as described by the concept of emergence. When this happens, the combined interactions of the various component agents can form a new agent as seen from a higher level, called a meta-agent, which is best described in terms of their group properties, such as a school of fish, a forest, a military formation, or an ocean wave.[34] These meta-agents can combine with other meta-agents to form even higher level meta-agents, with new aggregate properties that are adaptive as well. In this case, the complexity of the interactions of the meta-agents may be very different in nature to the interactions of the parts. For example, the dynamic complexity of the individual fish moving within a school of fish may be much higher than the dynamic complexity of the school itself relative to its surroundings. In this case, it is often most useful to treat the meta-agent individually, focusing on the collective properties of the whole rather than the individual properties of the parts. This is perhaps one of the key concepts of complexity theory, providing insights that cannot be as easily discerned by traditional analytic methods of linear inquiry.

Meta-agents not only tend to act as a separate component within a larger system, they also help us to create cognitive models that improve our ability to deal with added complexity. Meta-agents, also described as "gestalts", allow us to reduce the complexity we perceive by seeing the

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[33] Steven Johnson, *Emergence* (New York: Scribner, 2001), 16.

[34] Holland,11.

emergent properties of complex interactions as a coherent "supersignal" that lends itself to pattern recognition. This ability to emphasize the whole over the parts helps to prevent us from getting confused by seeing a disaggregated multitude of contours, surfaces, color variations; it is this principle that that allows us to recognize acquaintances amongst large crowds of people.[35] While we may not be able to describe the individual ears, eyes, or noses of our friends, we can recall the combinations of their faces for a lifetime, and we can even usually detect friends in a crowd by the way they walk, even if we can't see their faces.

Control of Complex Systems

In 1970 Ross Ashby, a pioneer in the realm of cybernetics and complexity, coauthored an article proposing that "The design of a complex regulator often includes the making of a model of the system to be regulated. The making of such a model has hitherto been regarded as optional, as merely one of many possible ways…under very broad conditions, that any regulator that is maximally both successful and simple must be isomorphic with the system being regulated."[36] This would later be described mathematically as Ashby's Law of Requisite Variety, which stated that to completely control a complex system made up of independent variables, the system of controls must be equally complex, with at least one control element per variable in the system.[37] In most systems, the high number of interconnected variables precludes the possibility of exercising total control, but the principle yields a key

[35] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations* (New York: Metropolitan Books, 1996), 39.

[36] Roger C. Conant and W. Ross Ashby, "Every Good Regulator of a System Must Be A Model Of That System," *International Journal of Systems Science* 1, no. 2 (1970): 1.

[37] W. Ross Ashby, W Ross Ashby Digital Collection, Estate of W. Ross Ashby,, HTML http://www.rossashby.info// (accessed 25 April, 2010).

insight nonetheless. If one wishes to exercise leverage on a complex system, and cannot control the system with one control per variable, the best one can hope to do is understand how the system interacts, and apply control where one can in the attempt to push the system in favorable directions and successfully compete against other actors in the system.

One practical demonstration of the implications of Ashby's Law occurs in the sport of ice hockey, in which a team is given an extra man advantage on the ice for every penalty the other team commits. Having more players on the ice than the other team doesn't automatically give the advantaged side total control of puck, but the greater the proportion of controls to the opponent's variables (the players in each case), the better the chance the "Power Play" team has to achieve positional advantage and get a clear shot into the opponent's net. Thus, while the teams may be equally matched in other levels of scale, such as recruiting, equipment, team revenues, player pay structure, intelligence and stamina of the players, etc., there is a mismatch in complexity at the level of scale defined by the system enclosed by the hockey rink walls. The extra player provides the Power Play team a greater ability to adapt to the emergent situation of the hockey game, and perhaps even a better chance to shape that emergence, as it is often demonstrated when the advantaged team can pass the puck around the periphery of the disadvantaged team's defense with relative impunity, waiting for a positional advantage to emerge which allows either an open or deflection shot at the goal.

Complexity vs. Scale

Another important concept from complexity theory is making a distinction between complexity and scale. Scale refers to "the number of

parts of a system that must act together in a strictly coordinated way."[38] Scale and complexity are interrelated, but describe different things. Generally, high scale operations are complicated due to the large number of interacting parts, but they do not always or necessarily have the adaptive qualities that lead to complex behavior. For example, a Swiss watch is complicated, but not complex as its pieces work together in a tightly coupled—albeit highly predictable—linear fashion. Likewise, a single organization can have varying levels of complexity at various levels of scale in its operations. For example, a surgeon in a hospital may have a highly complex job at the individual level, while the hospital administrator running the cafeteria relies on fairly predictable linear predictions of supply and demand to feed the surgeons, the patients, and hospital visitors every day. Large scale, low complexity operations actually benefit from linear approaches. The purpose of any bureaucracy is to create stability and reduce uncertainty, which is critical to operations which require diverse populations to move or process large numbers of items. The tradeoff for the predictability of bureaucracies is a loss of responsiveness at the local level.

Thus, there is a fundamental difference in the best approach to take—bureaucratic or adaptive— depending on whether your problems at a particular level of scale are complex, or merely complicated. Additionally, having to operate on various scales simultaneously can actually increase the overall complexity of an organization. As described by Dr. Alex Ryan, Assistant Professor for Complex Systems at the US Army School of Advanced Military Studies (SAMS),

> Solving complex problems is fundamentally different to solving complicated problems. Complex problems cannot be solved using techniques that are successful for complicated problems…However,

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[38] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 100.

> complex problems could be defined as those problems that cannot be solved at a single scale. They require coordination, multiple perspectives, and a systematic response because cross-scale effects interlink problems at different scales. [39]

In other words, there is a difference in the approach one must take in designing organizational schemes to handle different levels of complexity at different levels of scale. The challenge is that most organizations need to be able to cope with several levels of scale simultaneously, often with different levels of complexity at each level of scale. When one recognizes that one size doesn't fit all situations, the logical conclusion is that the organization must either develop specialized organizational mechanisms at different levels of scale, or it must be able to adapt locally to match the level of scale and complexity encountered.

Success at one level of scale is not sufficient to ensure success in the aggregate in a complex system. A hockey team that consistently scores on the Power Play can still be defeated in the long run if it cannot draw the spectators, advertisers, and merchandising that allow it to recruit and compensate players compared to other teams in the league. Off field indiscretions by either the players or the management can taint the team's image, making them less attractive to fans even if they are winning on the ice. And a team that both wins and preserves its image still cannot compete in the long term if the team's finances are mismanaged, or if the coaching staff cannot manage the mix of older experienced players with young talent through the recruiting and drafting processes.

Combining Ryan and Ashby's insights, we can then say that to control one's destiny to the maximum extent possible, a successful organization optimally matches its complexity at each level of scale *to the*

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[39] Alex Ryan, "The Foundation for an Adaptive Approach: Insights from the Sciences of Complex Systems," *Australian Army Journal* VI (Summer 2009): 77.

degree necessary to complete its required tasks, acknowledging the reality that it is seldom if ever possible to completely match the total complexity of the system and control it completely.[40] Thus, one must not only understand the complexity of the system one is operating in, but also design organizations and solutions that match it as closely as possible within economic constraints. Successful adaptation comes from bridging the gaps between different levels of scale and complexity in your operations – you've got to be able to manage all of the different levels of scale simultaneously, as success in one level of scale usually affects success in the others. As Antoine Bousquet states in *The Scientific Way of Warfare*, "The challenge …is therefore to harness the flexibility and adaptability of networks [decentralization] while preserving some hierarchical features—hybridization is the goal."[41] But must you choose between centralized and decentralized control in dealing with multiple levels of scale and complexity? Complex systems theory says no.

Centralized vs. Decentralized Control

If more complex problems cannot be matched by managing all of the individual components of the problem with a controlling function, then the only way to cope with that complexity is to adapt in order to control what can be controlled, and configure oneself to the greatest degree of advantage possible to deal with those things that cannot be controlled. As complexity often varies between levels of scale, the best way to deal with high complexity at lower levels of scale is to decentralize control, allowing local agents to respond to local conditions and successfully adapt. Complex systems theorists also offer a way to

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[40] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 67, 100.

[41] Antoine Bousquet, *The Scientific Way of War* (New York: Columbia University Press, 2009), 210.

pursue both approaches when faced with multiple levels of complexity at different levels of scale: by issuing centrally issued decision criteria to lower echelons. As Gharajedaghi describes it,

> …it's the *sharing of decision criteria*, not abdication of power, that results in empowerment and makes centralization and decentralization happen at the same time. Achieving a higher order of decentralized decisionmaking requires a higher order of centralized agreement on decision criteria.[42]

Thus, centralized command can be consistent with decentralized control, as it is in the case of the neuromuscular system in which the brain commands the body's movements, but a relatively small set of neurons direct the actions of the cells in any particular muscle.[43]

What Complexity Theory Does For Us

Complexity theory allows us to detect when a system that we are trying to influence—whether we're part of that system or competing with it—exhibits collective properties that do not lend themselves to linear approach solutions. When we fail to recognize complex situations, we often get the opposite result we intended, or are taken by surprise by unexpected side effects when our actions cause reactions that we did not anticipate. This is perhaps best exemplified by the US led invasion of Iraq in 2003, which adopted a very linear approach in its "race to Baghdad", but failed to account for the complex nature of Iraqi society which prevented the rapid overthrow of the Hussein regime from

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[42] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 72.

[43] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 110.

equating to victory.[44] In this case, the coalition was ready for high scale, complicated military operations, but they were not ready for the local complexities that would lead to different kind of insurgencies in different parts of post invasion Iraq.

When we do recognize different levels of complexity at different levels of scale, we can better match both our organizational methods and proposed solutions that give us a better chance of achieving our desired results. But we cannot propose practical ways to deal with complex systems unless we first understand the nature of systems in general.

[44] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 93.

Chapter 2

Systems Theory

While the insights of complexity theory give us a much better way to look at the larger picture, it's still difficult to channel those often esoteric insights into useful designs for strategies and organizations. This is where the language and concepts of systems theory can enhance the insights of the complexity theorists, giving us more precise tools to convert abstract concepts into practical applications.

Origins of Systems Theory

Like complexity, systems theory was borne out of the gradual realization that methods of linear reduction were inadequate to characterize complex interactions and the emergent properties that can only be seen in the aggregate. Peter M. Senge presents an optimistic view of systems thinking it in *The Fifth Discipline: The Art and Practice of the Learning Organization*,

> Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots". Systems thinking is the discipline for seeing the "structures" that underlie complex situations, and for discerning high from low level change…from seeing people as helpless reactors to seeing them as active participants in shaping their reality, from reacting to the present to creating the future.[1]

Systems theory is as nascent as complexity theory in the longer view of human inquiry, but unlike complexity it has already experienced three generations of thinking: operations research, cybernetics/open systems,

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[1] Peter M. Senge, *The Fifth Discipline: The Art and Practice of The Learning Organization* (New York: Doubleday, 1990), 68-69.

and design, it's most current concept.[2] Most modern systems theorists credit Austrian biologist Ludwig von Bertalanffy 1968 work *General System Theory* as the seminal work in their field. In it, von Bertalanffy stated that the same basic system principles could be applied to any system regardless of the composition of its components, and that the parts system could only be understood in terms of their role in the larger system.[3] Perhaps Bertalanffy's greatest contribution was the concept of the *open system*, a "living" system which resists equilibrium (entropy), and actually achieves higher levels of organization and activity by importing and converting energy from outside the system into complex structure.[4] Thus, all complex adaptive systems are open systems, and all closed systems are theoretical constructs that help us understand subcomponents of an open universe.

Systems theory defines specific problems in terms of elements that can somehow be controlled (the system), and those that cannot (the environment).[5] This allows systems thinkers to define the system as all of the interactive sets of variables that can be controlled by various actors, the environment as variables that influence the system but are not controlled by it, and the system boundary as a subjective construct defined by the interest and relative ability of the actors to influence parts of the system.[6] As systems theory has advanced, it has yielded

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[2] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 16.

[3] Ludwig von Bertalanffy, *General System Theory* (New York: George Braziller, 1969).

[4] Bertalanffy,124-126.

[5] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 30.

[6] Jamshid Gharajedaghi, 30-31.

additional insight into how variables previously thought to be unpredictable in the micro sense actually do exhibit somewhat predictable behaviors in the macro, and can sometimes be influenced even if they cannot be controlled. This group of variables is described as the transactional environment, in other words, the "gray area" between things you can control and things you can't.[7] By understanding how variables in the transactional environment act and, more importantly, why they do, systems theorists hope to bring a higher degree of prediction and control to the increasingly complex systems we face today.

Principles of Systems Theory

As with complexity theory, there is no commonly agreed on definition of all of the concepts included under systems theory. As complexity theory continues to merge with systems theory, the distinctions between the schools of thought continue to blur and overlap under the "catch all" of complex systems theory. It would be useful to review some of the key concepts of complex systems theory that originated in the systems thinking camp.

Multidimensionality

Despite the undeniable value of the insights that Sir Isaac Newton provided to science and our overall understanding of the world, the simple fact remains that nearly all of his insights were constrained to dealing with two body problems showing the effect of two independent variables on each other. Conceptually, it's very difficult to deal with more than two variables at the same time, and based on linear thinking, many variables tend to be described as opposites in a zero sum game.[8] In reality, every action is affected by an incalculable number of

[7] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 31.

[8] Gharajedaghi, 38.

independent and dependent variables in combination, and the relative effect of one variable on a system may depend heavily on which other interconnected variables are present, and even in what order they are reacting to one another.[9] Additionally, the same variable in a system may have multiple structures and functions within a system, and be governed by multiple processes simultaneously.[10] It is because of this multidimensionality that cyberneticist Garrett Hardin once remarked that "*we can never do merely one thing*" when we act in a complex system – the multiple interconnectivities in even relatively less complex systems will still create side effects that may be difficult to anticipate.[11] Thus, each decision to act must balance the benefit of the intended effect against the possible negative effects of our unintended consequences.

The effect of multidimensionality often overwhelms our ability to comprehend it, leading us to assume incorrect cause and effect relationships in complex adaptive systems, known as problems of inference. According to Axelrod and Cohen in *Harnessing Complexity: Organizational Implications of a Scientific Frontier*, the three most common problems of inference are:

- Mistakenly crediting or blaming a part of the system when the larger ensemble [meta-agent] is responsible
- Mistakenly crediting or blaming a particular ensemble [meta-agent] of factors when in fact a different ensemble is responsible

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[9] Robert Jervis, *System Effects: Complexity in Political and Social Life* (Princeton: Princeton University Press, 1997), 35.

[10] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 43.

[11] Robert Jervis, *System Effects: Complexity in Political and Social Life* (Princeton: Princeton University Press, 1997), 10.

- Crediting a misconstrued strategy, where the action involved produced success, but the conditions in which the action should be taken have been misunderstood. [12]

Despite these conceptual challenges, multidimensionality is not all bad news according to systems theorists. When one understands multidimensionality, one also understands that the mutual independence of seemingly opposing tendencies can be characterized by an *and* instead of an *or* relationship, and in combination with additional variables, can coexist and form complimentary relationships in a non-zero-sum multilateral relationship, like the concepts of freedom, justice, and security.[13] Because the tendency of scientific thought has been to think in dualities rather than multiplicities, we're often surprised when events go differently than we had predicted that they would.

Counterintuitiveness

Complex systems often seem to react in ways opposite to what we expect when problems of inference and attribution cause us to draw false conclusion about causality, or we underestimate the interconnectedness between elements within a system. Linear thinking often fails to anticipate the multiple results a single action can create, falsely assuming that one action will produce one result without causing others. Trying to solve for one problem at a time is called repair service behavior in systems theory, and usually leads to counterintuitive, often opposite results from the desired ends when performed in the context of a complex adaptive system. Repair service behavior in complex systems has two major failings: either the wrong problem is solved, or a solution

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[12] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), 139.

[13] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 39.

to a short term problem creates even bigger long term ones that only emerge later.[14] Repair service behavior's biggest failing is usually the assumption that the rules of the system will stay the same after the repair action is taken, but in complex adaptive systems, the act itself changes the rules of the game, often in unpredictable ways.[15]

Attractors

Studies at the Santa Fe Institute, New England Complex Studies Institute, and similar efforts have demonstrated that both living and nonliving systems have a capacity to adapt and evolve. How is it possible that DNA protein strands, slime molds, ants, and crystals all seem to have the capability to organize in complex ways, despite the fact that there is seemingly no central authority directing their actions? The answer is that something is pulling them in the direction of greater order, even if their response to the pull is not a conscious one. These forces which drive change in a complex system, whether they are physical forces or intangible concepts, are described in systems theory as *attractors*.

Attractors can either be physical forces, like gravity, or conceptual ones, like the human norms and values that drive the interactions of self organizing systems. Systems theorist Jamshid Gharajedaghi describes four different kinds of attractors:

- Point attractors: draw or repel thinking beings in pursuit of their natural instincts

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[14] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations* (New York: Metropolitan Books, 1996), 60.

[15] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 3.

- Cycle attractors: self maintaining dialectic tendencies between seemingly opposite but complementary tendencies like stability and change, order and chaos, etc.
- Torus attractors: goal seeking tendencies based on an image of what they ought to be, like DNA growth patterns in biological systems
- Strange attractors: self organizing and purposeful choices of sociocultural systems between choices of ways and means resulting in unpredictable patterns based on stylistic preferences of purposeful actors[16]

If these forces could be discerned, interdependence between key variables in the system might be better understood, thus allowing a degree of prediction at the macro even when it might not be possible at the micro level. Additionally, systems theorists posit that some attractors can be controlled or influenced, thereby increasing our ability to apply leverage on the system in the transactional environment. This is especially true of strange attractors such as norms, ethics, and cultural values, which act as constraining elements of the decision process.[17]

There is another formulation of attraction in a system that focuses more on influencing self organizing meta-agents, described in terms of centripetal and centrifugal forces. Economist Paul Krugman theorized that as cities form, there are certain forces that pull some businesses close to each other (centripetal forces) and others away from each other (centrifugal forces) as businesses simultaneously cooperate and compete with each other on a micro level for labor, land, and customers.[18] These

[16] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 52.

[17] Gharajedaghi,36.

[18] Steven Johnson, *Emergence* (New York: Scribner, 2001), 89-90.

forces at the micro level combine to drive an emergent higher level organization of multiple, similar, separate clusters of business centers evenly spaced from each other, despite the fact that there is no outside regulator forcing them to do so – in essence, "local rules lead to global structure – but a structure that you wouldn't necessarily predict from the rules."[19]

Cooperation vs. Competition

Centripetal and centrifugal forces can also be understood in terms of competition vs. cooperation between agents within a system, but systems theorists have even more insights to offer than a simple two dimensional model that the Newtonian terms suggest. While we often see competition and cooperation as opposite sides of a duality (exactly the trap that multidimensionality argues against), actors within a complex adaptive system simultaneously cooperate and compete with each other simultaneously, albeit with different approaches at different levels of activity. Professional athletes on the same team cooperate with each other so they can compete better as a team, but while teams complete on the field of play and in their recruiting efforts, they also cooperate with each other as a league against other sports by agreeing to common balancing rules and standards for paying salaries, marketing, recruiting, drafts, etc.[20] Thus, if one is looking to bring about conflict resolution, the systems perspective tells us that the key to dissolving conflict is to discover new worldviews and frames of reference at lower levels that create win/win possibilities for common higher level

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[19] Johnson, 90.

[20] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 67, 80-85.

objectives, thus making competition at lower levels healthy rather than destructive for both agents in the aggregate.[21]

Insights from Studies of Networks

In parallel with studies of complexity, studies of networks have greatly benefitted from modern advances, and yielded insights far beyond their initial explorations in the physical sciences. In recent years, new mathematical tools and computers have greatly accelerated research on networks in both the physical and the social sciences. This research has shown that networks have a number of very general properties that apply whether one is talking about a network of particle interactions, a web of neurons in the brain, or people in an organization.[22]

With the advent of real networks such as the Internet, and also virtual networks created in computer simulations, researchers have been better able to describe the way networks of all kinds form and interact. As networks in action are systems, we can refer to the building blocks as agents, variables, and hubs synonymously. While the language and approach between the disciplines may be slightly different, as Bertalanffy originally proposed, the logic is the same.

Network Emergence

Studies of complex networks indicate that complex, nonlinear networks grow very differently than linear ones, especially in networks bonded by information rather than physical connections. In linear networks the number of connections per node to other nodes tends to follow a bell curve distribution, with most nodes having close to the same number of connections. In nonlinear networks, also called scale free

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[21] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 69-71.

[22] Eric D. Beinhocker, *The Origin of Wealth: The Radical Remaking of Economics and What it Means for Business and Society* (Boston: Harvard Business School Press, 2007), 142.

networks, the relative freedom of nodes to connect across the entire system leads to a power law distribution, in which only a few nodes have very many connections, and most have very few. The difference between linear networks and scale free networks can be described by the difference between cities connected by highways, and cities connected by airports.[23] In the linear two dimensional world of the road system, each town has roughly the same number of roads coming in and out, radiating in all directions towards other towns. In the relatively unconstrained world of air travel, most air traffic operates out of a few key hub airports that are extremely large, and funnel traffic from smaller, less connected airports before sending travelers on to their final destinations. This same pattern of formation applies to most information bonded networks, like the Internet and the social networks it enables. But this power law growth is not random – forces of attraction determine which nodes will become critical, highly connected ones in the system.

Network Effect

As networks grow, there are natural tendencies for well connected nodes to become even more connected because of preferential attachment, which is the tendency to follow group patterns of behavior during free scale growth.[24] Under this principle, popularity attracts, and hubs in the network that become highly connected tend to become even more connected unless another more powerful attractor replaces it. One example of this was the social networking website Myspace, which rapidly gained popularity by word of mouth for a time, but then had its membership drop dramatically when Facebook emerged, offering users a

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[23] Albert-Laszlo Barabasi, *Linked: The New Science of Networks* (Cambridge: Perseus Printing, 2002), 71.

[24] Albert-Laszlo Barabasi, *Linked: The New Science of Networks* (Cambridge: Perseus Printing, 2002), 85.

more diverse blend of ways to keep in touch with their friends and associates. The emergent qualities that make one node more likely than another to become a highly connected hub in a network is described collectively as hub fitness, which is a relative measure of a specific hub's ability to stay in front of the competition in attracting links.[25] Thus, a node's importance in the system is determined not only by the number of connections it has, but also by the fitness that allows it to keep those connections in a competitive environment.

Local Bias

When a node has relatively few connections, or needs little variety to perform specialized tasks in a relatively benign environment, a phenomenon called local bias exists.[26] Isolated branches of networks have much less variety than the rest of the system, but due to the advantages of protection from competition can continue to survive with a more homogenous blend of nodes. This can be advantageous when specialization from the wider group is required, and the uniqueness of these protected niches can provide the larger organization with critical variety it needs for long term adaptation – this is the principle behind "think tanks" and "Skunk works" instituted in various organizations to promote innovation.[27] At first, this may seem counterintuitive - if variety is indeed good for adaptation, then why are you segregating your "big idea guys" into small, isolated offices? The key is using local bias in your favor, protecting the small group of innovators from the inevitable local

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[25] Barabasi, 95.

[26] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), 63.

[27] Eric D. Beinhocker, *The Origin of Wealth: The Radical Remaking of Economics and What it Means for Business and Society* (Boston: Harvard Business School Press, 2007), 366.

bias creep of the larger, relatively stable bureaucracy. By allowing small shops to operate outside of the wider norms of the larger group, a creative local bias within that shop is created, inoculating it from becoming homogenous with the larger organization. This makes it more likely that the larger organization can reach back into the Skunk works for the creative spark – variety - it needs to adapt when the competitive outside environment makes its the previous corporate configuration obsolete.

Critical Nodes

As a scale free network that describes most complex systems grows, a few hubs become so highly connected that they can exert a high degree of influence on the other nodes of the system. There can also emerge a series of connections in which one or more nodes becomes highly dependent on a specific hub, like branches of a tree depend on the limb they are commonly connected to for sustenance. It is the number and configuration of these critical nodes/key hubs that determines how resilient a system is to failure from outside shock. Stress propagation failure can occur when the failure of one critical node precludes the other nodes from functioning, and cannot be replaced by another one.[28]

Networks can avoid catastrophic failure in two ways. The first way is to partition certain parts of the system, keeping stress in one part from disrupting the entire system. This is the same principle between putting watertight hatches between all rooms in a ship, allowing them to be sealed up and written off if the hull of the ship starts to flood.[29] The second way to guard against system failure is to have redundancy, where

[28] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), 109.

[29] Axelrod and Cohen, 110.

the roles of one part of the system can be shared by or rapidly transferred to other parts of the system, maintaining key processes should one part of the system fail, and reducing disruptions from simple failures in one node.[30] Thus, in highly connected networks, simple failure is unlikely, and catastrophic failure usually requires a simultaneous disruption of several highly connected, key hubs to overwhelm the system's ability to transfer functions and adapt.

Coupling

The degree to which systems are highly connected, and how many connections there are between nodes relative to one another determines the degree of interdependence between the nodes. One of the challenges that complex networks present is that often, specific goals of a purpose driven system are supported by specific parts of the system, but other goals may require the same elements of the system at the same time, creating a competition between nodes of the system. The relative dependence of variables in the system thus creates dilemmas when the supporting criteria of two goals are not positively linked, and in complex systems, it's unlikely that all goals, and their associated system functions, will all be complimentary.[31] This is why in complex situations we can never do only one thing – in highly connected systems, processes compete to use the same nodes in different ways, and we can seldom solve for all of our problems at once.

In his book *Normal Accidents: Living With High Risk Technologies*, sociologist Chales Perrow proposed looking at the degree of interconnectedness between nodes of a complex system as *coupling,* a

[30] Albert-Laszlo Barabasi, *Linked: The New Science of Networks* (Cambridge: Perseus Printing, 2002), 111.

[31] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations* (New York: Metropolitan Books, 1996), 51-52.

term taken from engineering which describes the "slack or buffer or give between two items."[32] Applied to systems, loose coupling, or a weak interdependency between nodes, "allows certain parts of the system to express themselves according to their own logic and interests," where in cases of tight coupling, the actions in one part of the system are highly dependent on the others.[33] Coupling is not determined by the degree of organization or the number of interconnected variables, but rather how closely dependent they are on each other, and therefore tightly coupled systems are more prone to failure in the whole from failure in one part of the system.[34] Thus, the degree of coupling not only determines how resilient a system is to external shock, but what degree of control can be decentralized in the system.

Bureaucracy vs. Adaptability

While it might seem that loose coupling is always preferable to tight coupling because of its adaptive advantage, there are times when a tightly coupled bureaucratic organization is preferable. The primary advantage of tightly coupled, linear systems is that they provide stability and predictability, making it safer to conduct large scale "motherhood" functions like logistics and personnel functions that require efficiency to stay competitive by reducing costs and risks.[35] As previously discussed, complexity theory posits that a successfully adapting system must be able to shift between being rigid and flexible at different levels of scale. Systems theory asserts that this usually requires shared decision criteria

[32] Charles Perrow, *Normal Accidents: Living With High Risk Technologies* (Princeton: Princeton University Press, 1999), 90.

[33] Perrow, 92.

[34] Perrow, 92.

[35] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 124.

that give lower level echelons sufficient freedom to adapt to unique local conditions, but still maintain enough unity of effort between the subcomponents to ensure their mutual progress in the direction of the collective goals of the larger organization.[36]

What Systems Theory Does for Us

By understanding the basic operating principles of any system, one can better understand how some parts of systemic processes might lend themselves to prediction, influence, and exploitation. Even if one cannot understand the overall system, often a more specific understanding of parts of that system lends itself to better problem definitions and solutions, helping the strategist to understand the various competing interests and unintended consequences that might be associated with a proposed course of action (or chosen inaction). Having more accurate models of the real world chains of causation give strategists better approximations of cause and effect, reducing uncertainty and enabling the predictions that all strategies require. Understanding systems may also give the strategist a better feel for what cannot be predicted, which must be estimated and presented as risk.

[36] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 72.

Chapter 3

Practical Applications of Complex Systems Theory

The point of any theory is not just to explain *how* something happens, but to give insight on *why* it happens so that one may use this information for successful adaptation in the future. Context enables strategy, which uses its insights for prediction, anticipation, and action. As Irene Sanders points out in her book *Strategic Thinking and the New Science*,

> "In order to think and act strategically, we must first understand the context in which our decisions are being made…In the new planning paradigm, strategic thinking, the most important step in any planning effort, begins by stepping back and observing the environment as it really is, a complex system of interacting variables. Because the real environment is nonlinear, the strategic thinking must begin as a nonlinear, intuitive process. It must engage the powers of the most sophisticated information processor available today-the human mind."[1]

In other words, failure to account for the nonlinear and self organizing elements when formulating strategy is akin to "playing pool on a rugged pool table and expecting it to be completely smooth." But if one acknowledges the unevenness of reality, this "better understanding of the landscape can help to plot a better path that uses the gradients to advantage."[2]

Complexity theorists are not the first to recognize the need to account for nonlinearity in strategic decision making. In 1971, political

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[1] T. Irene Sanders, *Strategic Thinking and the New Science* (New York: The Free Press, 1998), 4, 138.

[2] Alex Ryan, "The Foundation for an Adaptive Approach: Insights from the Sciences of Complex Systems," *Australian Army Journal* VI (Summer 2009): 78.

scientist Graham Allison proposed three separately focused but complimentary conceptual models to analyze political decision making, which inherently implied that political decisions are emergent properties not understandable solely in the context of a predictable, linear decision process understood by following the lines in the defined chain of command.[3]

The Challenge of Complexity

Complex systems present significant challenges to human organizations trying to operate within and among them, and for the leaders who try to direct the activities of complex organizations. Political pressures to act and act quickly often tempt decision makers to label complex problems as simple ones; declaring "a War on" anything is perhaps the most universally recognizable application of this principle.[4] In trying to grasp a group of separate problems under a bumper sticker description in order to deal with one problem more easily, we often fail to solve for the separate but related underlying problems in a non-systemic repair service type of approach, or fail to define which aspects of the system we would like to keep unchanged, and in doing so create new, unanticipated problems with our quick fix solutions.[5] The more dynamic the system, the greater the time pressure to act before one understands the broader situation. This often leads to solving for symptoms rather than the core underlying problems, creating unintended second and

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[3] Thomas J. Czerwinski, *Coping With the Bounds: A Neo Clausewitzian Primer* (Washington DC: DoD Command and Control Research Program, 2008), 28.

[4] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations* (New York: Metropolitan Books, 1996), 55.

[5] Dörner, 63.

third order effects that may ultimately be worse than the original problem.[6]

Inflexible organizational constructs and tendencies can also hamper our ability to adapt to the challenges of a complex system. Gaining the consensus needed to develop social systems and large organizations takes time, and while decisions about the shape, structure, and strategy of an organization are being made, the rules of the game continue to change, causing a disconnect between you planned actions and desired results. The reason that so many of yesterdays successful businesses often become irrelevant or go bankrupt in only a few years is evidence of the difficulty with which large organizations have in maintaining competitive advantage in face of such changes – their very act of being successful changes the game as others adapt to better compete with the market leader. Gharajedaghi identifies five forces that make “failure out of success” in organizations operating in a complex adaptive world:

- *Imitation*: competitors can often seize on your innovations without paying for the development of them and find competitive advantage or steal market share. “Advances in information technology, communication, and reverse engineering have increased product technology’s vulnerability to imitation.”
- *Inertia*: Advocating for change in large organizations with heavy investments in sunk costs and obsolete conceptual concepts is difficult, thus “the likelihood that an organization will fail to respond to a critical technological breakthrough is directly proportional to the level of success it had achieved in a previously dominant technology.

[6] Dörner, 40.

- *Suboptimization*: Assuming that the formula for yesterday's success still applies today discourages adaptation to new realities. "An increasingly monolithic culture produces an ever-decreasing set of alternatives and a narrow path to victory"
- *Change of the Game*: Your actions cause reactions in the system, which over time decrease competitive advantage. "The act of playing the game successfully changes the game itself".
- *Shift of Paradigm*: the very way that we view the universe occasionally has to change, but it takes time to recognize this. "Not only has there been a shift of paradigm in our understanding of an organization as a biological model to a sociocultural model-but there has also been a profound shift in our assumptions regarding the method of inquiry, the means of knowing , from analytical thinking (the science of dealing with *independent* sets of variables) to *holistic thinking* (the science of handling *interdependent* sets of variables). [7]

Using Systems Concepts to "Harness Complexity"

In *Harnessing Complexity*, Axelrod and Cohen describe their book's title as "acting sensibly without understanding fully how the world works."[8] While we can never precisely predict or control the interactions of complex adaptive systems, this does not mean that we are entirely helpless to act when confronted with them. It simply means that we must be able to match our strategies and structures to best fit the changing environment at the levels of complexity we encounter. In his groundbreaking book on applying complexity theory to economics, Eric

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[7] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 4-9.

[8] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), 45.

D. Beinhocker offers a method to deal with uncertainty in a complex environment:

> While Complexity Economics strips away our illusions of control over our economic fate, it also hands us a lever-a lever that we have always possessed but never fully appreciated. *We may not be able to predict or direct economic evolution, but we can design our institutions and societies to be better or worse evolvers*…evolution may indeed be cleverer than we are, but rather than outsmart it, we can understand it and harness its power to serve human purposes.[9]

The way to do this is to create an environment where evolution can take place, by designing social systems and the technological systems that support them to foster variety, sense the environment accurately, and to use the variety of individual subagents to seek competitive advantages that work towards the common vision of the organization.[10]

Ideally, an organization should attempt to solve for as many competing problems as possible at once, but when constrained by time and resources, it should seek to understand common interdependencies of the system, distinguish problems in terms of centrality, importance, and urgency, and delegate authority to deal with the problems at the lowest level possible.[11] In an adaptive environment, the key to understanding emergence "has always been about giving up control, letting the system govern itself as much as possible, letting it learn from the footprints."[12]

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[9] Eric D. Beinhocker, *The Origin of Wealth: The Radical Remaking of Economics and What it Means for Business and Society* (Boston: Harvard Business School Press, 2007), 324.

[10] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 92.

[11] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations* (New York: Metropolitan Books, 1996), 55-56.

[12] Steven Johnson, *Emergence* (New York: Scribner, 2001), 234.

Aids to Learning

The attempt to "harness complexity" has been the driving theme of complex systems theory applied to many fields, and just as the various systems that these theories describe are similar in nature, so too are the positive actions that one may take in order to better prepare for the demands of evolution. Without these tools, the challenges of a complex adaptive system may overwhelm. But even in highly complex adaptive systems, there are several "aids to learning" that can help translate the theoretical concepts to useful practical applications.[13] Taking insights from complexity and systems theories, we can design strategies and organizational schemes that help us control what we can, account for what we can't control, and exert influence in the transition region in order to increase the chances of favorable outcomes. Indeed, with only a few aids to learning, we can improve agents' abilities to cope within complex environments, and perhaps even to thrive in them.

Leading in Complex Environments

A systems theorist's definition of leadership says volumes about his worldview.

> Slowly, we are realizing that we do not actually control much of anything, but do have the ability to influence many things…Managing a system is, therefore, more and more, about managing its transactional environment, that is, managing upward. Leadership is, therefore, defined as the ability to influence those whom we do not control.[14]

This viewpoint recognizes that while coercion by force is always possible in limited amounts, the vast majority of social connections between humans are "information-bonded", "a voluntary association of purposeful

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[13] Thomas J. Czerwinski, *Coping With the Bounds: A Neo Clausewitzian Primer* (Washington DC: DoD Command and Control Research Program, 2008), 49.

[14] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 32.

members in which the bonding is achieved by a second-degree agreement, which is an agreement based on a common perception."[15] Such perceptions are usually based on common cultural values, norms, and social conventions, but are seldom enforced absolutely, and far more often depend on these "strange attractors" to keep the social relationships in force, and the degree of membership in a community depends on to what degree the member shares the image of the group.[16] Thus, the success of leaders depends on their ability to convince other people to adopt and work for their own worldview, "The world is not run by those who are right. It is run by those who can convince other that they're right."[17]

It is with this perspective that we can start to look at organizations not only as social constructs, but also as information sharing networks that can be influenced by many of the same forces that shape networks. Even if the mechanisms or interactions are not identical, the metaphors are extraordinarily useful whether one is talking about a network of neurons in the brain, a network of computers, or the structure of a corporation.

People and Organizations as Hubs and Nodes

Any agent, or group of agents working together within a complex adaptive system, needs several kinds of information in order to respond to its environment and successfully adapt to it. Just as an agent in the system is guided into higher level aggregate emergent behaviors by attractors, people are guided by the strange attractors of shared vision, norms, rules, and a feeling of belonging. The vitality and adaptability of

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[15] Gharajedaghi, 83.

[16] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 85.

[17] Gharajedaghi, 37.

a human system depends on rests within the characteristics, talents, skills, and knowledge of the humans that comprise a social network, which combine to offer the variety so crucial for successful adaptation to changing environments. People with personalities, education, and training suited to managing relations between different social groups can be seen to exhibit “hub fitness”, allowing them to serve as “superconnected hubs” for spreading information throughout human networks. Just as they do in other networks, the “loosely coupled” connections facilitated by the movement of these superconnected individuals moving somewhat randomly among larger groups can generate and spread variety – it is these people that can most often turn a chance meeting at the water cooler into a creative collaboration, or share key bits of information randomly gathered with the stakeholders who would not normally work outside their niche group.

Thus, people specifically identified, prepared, and tasked to serve in this interactive role can facilitate new connections between otherwise homogenous social groups, adding additional variety and creative possibilities for recombination and synthesis. Certain members of society, due to their social position or ability to establish rewards and punishments, serve as attractors on certain parts of the system, and use their powers of selection – admission to a group and promotion – to control the variety or conformity of the group. Understanding the difference between the personal characteristics of the people, and the positioning within the system that makes them effective, can allow us to better recruit, train, and reward those who can best manage the flows of creative variety within and between organizations.

Deliberate Control of Tagging

Network analogies can also apply to the way people identify and relate to each other. Tagging, in the form of uniforms, ID cards, passwords, rank and specialty insignia, enables groups to organize and

specialize, and also to separate their processes from others. The awarding of academic degrees and professional certifications is another method of tagging, indicating that a person with this recognition has a certain set of qualities that allow them to perform in specific roles and duties. Such tags are routinely used to manage selection in human systems, as well as to determine which people have access to certain positions and sources of information. Once seen in this light, the interaction of social networks can be institutionalized into deliberate institutional constructs, tailoring the human network according to the complexity of its task.

Managing Novelty

If adaptation is the best way to deal with complexity, then it would seem that having the most variety possible would always be most advantageous. Ironically, this is not the case. When all of the agents in a system are highly connected, early innovations can spread too fast, eliminating “islands” of protected local variety that will later be crucial for adaptation. This phenomenon describing the long term disadvantages of having an overly homogenous system is known as “premature convergence”.[18] On the other hand, healthy adaptation requires that neighbors in a system end up “stumbling across each other” – it is these relatively random collisions of unlike agents that promote the variety needed to compete within a complex adaptive system.[19] Thus, conscious choices to isolate some groups within an organization can be important to guarding against overextension in the near term, and lack of novelty for adaptation in the long term.

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[18] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), 92.

[19] Steven Johnson, *Emergence* (New York: Scribner, 2001), 79.

Another way that organizations can control their variety is by balancing exploration versus exploitation. Having the capability to sense what is emerging in the environment, and adapt oneself to benefit from changes as they are occurring, is a source of competitive advantage, and purposeful environmental scanning can help to increase variety.[20] Exploration is one means of sensing initial conditions early, with the intent of detecting emerging patterns and trends early, before they erupt as a strange attractor for which your system is unprepared, or help you identify new opportunities in the system that other competitors are not yet exploiting.[21] But in a system of limited agents, allocating some for exploration also has opportunity costs when the same agents could be used to exploit knowledge of current conditions, improving fitness in the short term.

Enhancing Pattern Recognition

The key to successful adaptation is to have the ability to sense the environment, compare it to the desired state of the system, and make appropriate adjustments to create competitive advantages. This implies that any adaptive system must not only be able to sense information, it must have the ability to apply it to specific contexts.

> The body learns without consciousness, and so do cities, because learning is not just about being aware of information; it's also about storing information and knowing where to find it. It's about being able to recognize and respond to changing patterns… [22]

These patterns represent "structural knowledge", or knowledge of how the variables in the system are related and how they influence one

[20] T. Irene Sanders, *Strategic Thinking and the New Science* (New York: The Free Press, 1998), 63, 110, 112.

[21] T. Irene Sanders, *Strategic Thinking and the New Science* (New York: The Free Press, 1998), 74.

[22] Steven Johnson, *Emergence* (New York: Scribner, 2001), 103.

another, that forms the model of reality that the system uses to anticipate and adapt, in turn forming the basis of intuition.[23] It is the ability to amass long term patterns of life that provides even non-sentient living systems a greater capacity to detect emerging patterns in the environment and successfully adapt to them—the more information that is collected, the more accurate that predictive models for adaptation tend to be.[24] Thus, to increase the chances for successful adaptation, both exploitation and exploration should be pursued, balancing the imperatives of successfully adapting in both the short term and long term.

Selection Criteria

While performance measures are important for sensing the environment, it is important to understand that they actually can *change* events as well. By choosing specific aspects of the environment and the system's performance for measurement, and assigning selection criteria to them, the directors of the system create a strange attractor that drives the emergent activity of the system, as described by the saying "what the boss measures gets done".[25] Feedback and performance measures also can control the amount of competition versus cooperation between various aspects of an organization, allowing leaders who set them to control the nature of the interactions between various parts of the organization, even if they cannot control the specific results.[26] Managing

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[23] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex situations* (New York: Basic Books, 1996), 41.

[24] Johnson, 81.

[25] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (United States of America: The Free Press, 2000), 121.

[26] Axelrod and Cohen, 141.

interaction rules is crucial to tailoring organizations to have the right mix of independence and interdependence when dealing with different levels of complexity at different levels of scale.

Managing Interactions and Flows

One of the key insights of complex systems theory is that in complex environments, the rapidly changing nature of both the environment and the organization preclude the successful use of linear solutions and micromanagement. In creating organizations that can execute adaptation well rather than predetermined functions, it becomes more important to manage the interactions between parts of the system rather than individual actions.[27] This requires leaders of an adaptive organization to understand which patterns of interactions and information flows lead to organizational success in the aggregate, and also to look beyond current activities to consider if the pattern of activity must change to adapt to emerging challenges.[28] Changing interaction rules gives managers and leaders some control over these interactive processes, but should be set in the context of the success of the entire system, taking as many pieces of the system into account as possible.[29]

Multidimensional Models

One of the difficulties even when one can successfully think in terms of complex systems is communicating your insights to others. Communicating even basic linear ideas, like driving directions, can be challenging enough - how does one handle the task of describing one or

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[27] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 69.

[28] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004), 114.

[29] Dietrich Dörner, *The Logic of Failure: Recognizing and Avoiding Error in Complex situations* (New York: Basic Books, 1996), 22.

more complex adaptive systems interacting? Luckily, many of the same tools that help us to understand complexity can be used to develop better decision support tools.

Too often we settle for one dimensional snapshots to determine our progress in a multidimensional world moving in time. One can tell something about the weather by seeing a single, monochrome snapshot of weather radar, but we can tell much more when we add color to distinguish between different types of precipitation. We can learn even more if we superimpose this image over a representation of US coastlines, state boundaries, a major cities, and major road systems. But even with all of this information, our ability to predict the weather is severely restricted even in the short term. But there is one thing we can do on most internet weather maps that tells us more about a weather system than anything else. What is it? We can set the map in motion, and use a visual depiction of the weather system's trends over time to predict what it will do and where it will go next. It is this dynamic picture of the environment, presented in a manner that conveys its multiple aggregate qualities in a way that our brains can quickly process, that best tells us if we should pack sunscreen or an umbrella.

Leverage Points

Having multidimensional, dynamic models of systems helps us to see emergent patterns occurring when certain variables interact along varying timelines, and may be the key to developing insights as to which parts of the system are critical to the others, making them potential points of leverage if we can control or influence them.[30] If one understands how systems are coupled, and which nodes are critical ones with the greatest "pull" on the others, we can often exploit this knowledge

[30] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 50.

to use these hubs to our advantage, or replace them with fitter hubs of our own design. Developing tools and systems that allow us to quickly communicate complex ideas is vital to exploiting points of leverage, especially as complexity increases while the time we have to orient ourselves within the system stays the same.

Visual Thinking

Even without the advanced technology of computer systems to provide animated, multidimensional models, we can still use two dimensional products like whiteboards, butcher paper, and office software to convey complex ideas. One way to do this is to utilize visual thinking, which Irene Sanders describes as "the ability to create and interact with images in one's mind", which allows one to "…create a picture or model of the problem in their mind, play with it, move it around, work with it, refine it, and use it to raise more questions."[31] This may also involve drawing a visual map of various concepts, and then looking at them simultaneously to search for associations that might be difficult to arrange in the mind. If one makes an actual model of a system with moving pieces, one can literally push various concepts or parts of the system around, using the visual cues to assist mental associations within the mind. (See Annex A for a description of how visual thinking methods were used to write this thesis.)

Takeaways for Dealing with Complex Systems

Just because we cannot predict or control the outcomes in complex adaptive systems with certainty does not mean that we are doomed to uncertainty and helplessness. On the contrary, with some basic understandings of complex systems, we can often steer the system in directions that favor our desired outcomes, and conform our

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[31] T. Irene Sanders, *Strategic Thinking and the New Science* (New York: The Free Press, 1998), 87, 93.

approaches to the things we can't influence. Gaining a better understanding the difference between what you can control, and what you can't, is perhaps the key to "harnessing complexity", and reflects a parallel search that military theorists have struggled with for centuries as they tried to reconcile the unchanging nature of war with its ever changing character. As well see in the next chapter, complex systems theory can give military theorists new lenses with which to examine age old questions about war, the most extreme mechanism used to attempt to control and influence the complex adaptive systems of human societies.

Chapter 4

Complex Systems Theory Applied to Military Theory

War has always been an emergent phenomenon, comprised of countless, constantly interacting physical and cognitive elements of individuals, groups, societies, and nation states competing violently for power, influence, and access to resources. If war is the sum total of these multiple levels of competition, can war be any less complex than any of the phenomena that play a part in it?

While there have been entire schools and institutes dedicated to specific areas of science, there are still remarkably few dedicated to a comprehensive study of war and warfare, and those that exist usually can influence only small parts of the military in the short term. Leaders who actually fight wars are not always familiar with the latest theoretical concepts being developed, and traditionally fall back on older concepts they learned during their formative years that may have occurred two or more decades before they assumed their current commands. Numerous new concepts have claimed to revolutionize warfare, but then fell short of their claims in action. Because of this, today's senior leaders are understandably reticent to adopt new ideas that claim to replace rather than to enhance the tried and true theories and principles that have guided military leaders for millennia. But a real revolution does not make what was true in the past suddenly false—Copernicus' insight that the earth revolved around the sun rather than the opposite did not change the fact that it rises in the east and sets in the west. Rather, a true revolution changes our understanding of why something is true.

Any new theory should not only replicate the success of the old ones, but should also explain things that the previous theories could not

account for, and also do it in a more elegant manner, a concept described as “Occam’s Razor”.[1] Claims that any new theory will “change the nature of war” should rightfully be looked upon with suspicion. But complex systems theory makes no such promises, complex systems theory gives us a better way to look at the nature of war that has always existed, with the *nature* defined as the basic interaction rules of human systems that don’t change, and *character* defining the interactions themselves which can change. Complex systems theory explains many of the key insights of the classical military theories, and also offers new ways to both expand on their original insights and correct some of their deficiencies.

The following discussion will demonstrate that the major insights of the most significant military theorists are consistent with complex systems theory, and even the seeming disconnects between prescriptive and descriptive military theories can be somewhat reconciled when described in terms of linearity and nonlinearity. It will also show how partially understood systems concepts, and mismatches between linear and nonlinear concepts, have led to most of the recent upheaval in operational design. Finally, the chapter will discuss how military organizations are using the new tools offered by complex systems theory to overcome the deficiencies of discredited concepts from the recent past, and design new methodologies that match reality more closely than traditional planning concepts.

This chapter does not claim to be an all inclusive catalog of all historical or current applications of complex systems theory in military though, but seeks to familiarize the reader with the most notable and relevant ones in both past and present times in order to show the

[1] Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009), 99-100.

timeless applicability of complex systems theory, in contrast with other now discredited fads in military thought. In short, using complex systems concepts as the foundation of military theory is nothing new, but our dawning recognition of this currently constitutes the leading edge in military thought.

The Ancient Military Classics

Thucydides' *History of the Peloponnesian War* and Sun Tzu's *The Art of War*, both written approximately 2400 years ago, are ancient classics of military strategy that have maintained their relevance in modern times. Representing Western and Eastern thought respectively, the authors describe war from two very different perspectives. Using the lenses of complex systems theory, we can see that these different approaches are actually complimentary, describing different aspects of the same complex human systems.

Thucydides

Thucydides, the Athenian defeated by the Spartan general Brasidas at Amphipolis in the Second Peloponnesian War, can validly claim to be the first military historian and strategist of significance in the Western tradition. Detailing the twenty seven years war between the Athenian Delian and Spartan Peloponnesian Leagues that ultimately led to Greece's subjugation by foreign powers only decades later, Thucydides captures the dynamics of two very different societies competing against each other for power and influence over the Ancient Greek world. In writing his account, Thucydides not only records the factual details of the war, but also captures the essence of the strategies adopted by both sides, usually in the form of expository speeches attributed to key leaders and delegations from the conflict. What has made Thucydides history most relevant is its richness in historical examples that illustrate universal concepts of war and politics, leading statesmen as prominent as George C. Marshall to endorse it as a virtual prerequisite for

understanding international relations.[2] In addition to all of these things, Thucydides also provides numerous historical validations of some of the key concepts of complex systems theory applied to war and warfare.

Among Thucydides' most famous contributions is his proposition that the actions of individuals, groups, societies, and states can be understood in the context of an attempt to simultaneously balance the prioritized social forces of fear, honor, and interest.[3] In complex systems terms, these are the powerful strange attractors that guide all basic human interactions, with fear being the primary motivator geared toward survival, perceived interest guiding actions when survival is assured, and honor providing motivation when the previous two imperatives are satisfied. While an understanding of these attractors cannot guarantee accurate prediction of individual decisions in specific instances, they can often be used to describe and predict human behaviors in aggregate, as well as in the long term. These strange attractors indicate the internal coding that most humans share regardless of culture as they compete with other individuals, societies, etc. In terms of complex systems theory, Thucydides motivations provide insight into the basic programming of humanity's individual and collective cognitive models of how the world ought to be, guiding their adaptation in competitive environments. If you know something about these models, you can anticipate the adaptations as people take actions in the attempt to make their environments match their models. This serves as the foundation for prediction that all strategy relies on.

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[2] Paul A. Rahe, "Thucydides as Educator," in *The Past as Prologue*, ed. Williamson Murray and Richard Hart Sinnreich (New York: Cambridge University Press, 2006), 99.

[3] Thucydides, *The Landmark Thucydides: A Comprehensive Guide to the Peloponnesian War*, trans. Richard Crawley (New York: Simon and Schuster, 1996), 43.

As humans are both individually and collectively complex, none of these three competing priorities is diametrically opposed to the others, meaning that just as in any complex system, we can never solve for one without influencing the others. The story of Athens and Sparta itself is a classic case of two complex adaptive systems competing against each other within the larger complex adaptive system of the Ancient Mediterranean and Persian worlds. Athens was a trading seapower, protected by its navy, impregnable walls surrounding its capital, and the ability to subjugate or influence other city states to provide it with the raw materials needed for sustenance. Sparta was a landlocked regional hegemon, protected by its army, and supported by a slave-based agrarian economy kept in check by an elite warrior class. For years, the two sides clashed with futility, neither side being able to overcome the strengths of each other, in what students of military strategy describe as "elephant vs. whale" stalemate. Then, both sides began the process of adaptation, each adopting the means of the other in order to break through the defenses of the other, and ending ironically when the land power, Sparta, defeated the sea power, Athens, in a decisive naval engagement.

How did they accomplish this? The Spartans, realizing their lack of variety in naval warfare, reached out to their traditional enemies the Persians to gain the maritime technology and expertise necessary to compete at sea. Athens attempted to achieve parity on land by reaching out to Argos, but failed, never successfully adapting to the demands of land warfare against Sparta after Argos was defeated separately by the Spartans. In the end, Sparta adapted more successfully, and ultimately won over Athens. But in winning, Sparta illustrated another key takeaway from complex systems theory: in complex adaptive systems, you can "never do just one thing." In making an alliance with Persia to defeat Athens, Sparta weakened the entire alliance of Greek city states

that had traditionally banded together to defend the region from foreign invasion. Only decades later, after even more Greek internecine warfare, all of the Greek city states eventually fell separately to Phillip of Macedon and his son Alexander the Great.

Thucydides does not set out to describe either military strategy or complex systems theories, but his historical rendering of the war between Athens and Sparta is rich with metaphorical examples that give evidence of the validity of both. In the end, the stalemate was broken by the side that successfully sought variety and adapted successfully, just as the theories of complex systems predict. But the real admonition of Thucydides in writing is book may be his warning echoed by the most important principle of complex systems. If your own definition of the system is too narrow, as was both the Athenian and Spartan definition of victory, your solution set will be to narrow. While the most obvious tie between Thucydides and complex systems theory is the importance of successful adaptation, perhaps the most important one is this: if you fail to understand how competition and cooperation work at various levels of scale, you cannot hope to adapt successfully within the context of the larger system. Because both Athens and Sparta failed to realize that their competition with each other jeopardized the vital cooperation of the Greek city states against outside powers, both ultimately lost their power to control their own destinies. For this reason, the high water mark of Greek society continues to be measured on majestic but crumbling marble pillars that continue to deteriorate centuries after Greece's high point of splendor.

Sun Tzu

While scholars cannot agree on whether or not *The Art of War* was the work of one author or many, this Eastern classic has achieved newfound popularity among both military thinkers and the business community in the last three decades. Sun Tzu is very possibly the

earliest known advocate for systems thinking in warfare, as a holistic understanding of the system and the environment in which a military commander competes is crucial to success according to his theory. If the acme of skill is to win without fighting—by first defeating the enemy's strategy, as Sun Tzu suggests—then one must not only be able to adapt oneself to the situation and the enemy, but also be able to predict how the enemy is adapting, and factor that into your own model for adaptation.[4] The Eastern way of war encapsulated by Sun Tzu is also very different from the Western, in that rather than trying to devise plans and impose them on the environment, the Eastern general seeks to use the inherent potential of the environment in his favor, using deception to maneuver the enemy into positions of geographic and material disadvantage that can then be exploited with minimal effort and risk. This Eastern concept is described by Francois Julien as seeking "efficacy."[5]

To achieve efficacy, the Eastern general senses both the situation and configuration and also the potential in the environment, and then seeks to maneuver one's opponents into a position that allows that potential to defeat him with minimal effort. Success comes not so much from one's active efforts, but rather from the situation enfolding: "For what counts is no longer so much what we personally invest in the situation, which imposes itself on the world thanks to our efforts, but rather the objective conditioning that results from the situation: this is what I must exploit and count on, for it is enough, on its own, to

[4] Sun Tzu, *The Illustrated Art of War*, trans. Samuel B. Griffith (New York: Oxford University Press, 2005), 115.

[5] Francois Jullien, *A Treatise on Efficacy: Between Western and Chinese Thinking*, trans. Janet Lloyd (Honolulu: University of Hawaii Press, 2004), 8.

determine success. All I have to do is allow it to play its part."[6] Successful generals recognize the fundamental nature of the system and the environment, and pattern their actions (or inaction) to take advantage of three different potentials: moral potential, topographic potential, and potential of adaptation. It is the third of these aspects of potential that the maneuver of military forces can influence. The potential of the situation cannot be anticipated, as it "proceeds from continuous adaptation…"[7]

While the likelihood of actually implementing a strategy based on efficacy may be suspect, due to the infeasibility of having sufficient ability to sense the nature of a complex adaptive system, the notion behind it presupposes the same kind of knowledge of the system that is sought in complex systems theory. It is, in essence, a theory based on harnessing emergence, or in other words, identifying key points of leverage in a system, controlling what one can, and adapting one's self to exploit the aspects of the system that cannot be controlled.

Prescriptive Theories of War

Various military writers, from Vegetius to JFC Fuller, have sought to offer prescriptive principles that can be used to make warfare more predictable and manageable. As best illustrated in the works of Antoine Jomini, prescriptive theories recognize that there are "decisive points" that have a greater impact on the system than others, and should therefore be the focus of one's efforts in warfare.[8] Additionally, certain aspects of the system do form linear relationships. At certain levels of

[6] Jullien,17.

[7] Francois Jullien, *A Treatise on Efficacy: Between Western and Chinese Thinking*, trans. Janet Lloyd (Honolulu: University of Hawaii Press, 2004), 23.

[8] Baron De Jomini, *The Art of War*, trans. Capt G.H. Mendell and Lieut. W.P. Craigshill (Radford: Wilder Publications, LLC, 2008), 63.

scale, linearity has the advantage of providing stability, and some aspects of the system can be approached in a sequential manner to influence events downstream. While these theories based on linear interpretations of the world are often useful, they just as often overreach in their claims to be able to control the whole of the complex adaptive system that is warfare, and often fail to account for the physical and moral forces that determine the emergent qualities of war. In doing so, military strategists often fail to anticipate the long term systemic results of their actions, and find that their tactical successes do not yield ultimate strategic success. It was this point that Carl Von Clausewitz seized in his landmark work *On War*.

Clausewitz and Complexity

If Thucydides and Sun Tzu equate to the Old Testament among the virtual cannon of military "Holy Writ," then Clausewitz's *On War* surely represents the most important book in its equivalent of the New Testament. And very much like the study of scripture, various interpreters have seized on individual words, concepts and translations in order to claim Clausewitz as support for their particular sets of beliefs about the nature and execution of war. Written as a reflection on his observations from personal involvement in the Prussian defeats at the hands of Napoleon, and later victories against him, *On War* is still seen by most modern military thinkers as the most comprehensive examination of the phenomenon of war to date. Clausewitz did not offer a formula for success that would work an acceptable percentage of the time even for the mediocre leader steeped in prescriptive rules of thumb. Rather, he painted a description of war that was far more unpredictable and complex.

Clausewitz's multidimensional view of the world can perhaps best be described by his famous "paradoxical trinity" of war, "…composed of primordial violence, hatred and enmity, which are to be regarded as a

blind natural force; of the play of chance and probability within which the creative spirit is free to roam; and of its element of subordination, as an instrument of policy, which makes it subject to reason alone."[9] He goes further to say that "Our task therefore is to develop a theory that maintains a balance between these three tendencies, like an object suspended between three magnets."[10] Thus, Clausewitz deliberately proposed a nonlinear model for the phenomenon of war, one in which the three main strange attractors pull simultaneously in different directions, with the position of the phenomenon of war as an emergent property influenced by, but not defined by, the resultant of the pulls from each tendency. He includes both physical and conceptual elements to describe the system of war, and acknowledges that chance and probability are inevitable in a complex system where agents "roam" and randomly interact with each other. At the same time, there are elements of the system that are subject to reason, providing points of leverage that can be influenced with some measure of predictability.

While most students of military strategy acknowledge the genius of Clausewitz, most of the debates on the validity of his works center on the methods and terms that he uses to describe the complex phenomena of war. Limited by the Newtonian scientific concepts of his times, and the Hegelian dialectic which attempts to achieve synthesis by comparing two extremes of a concept between thesis and antithesis, Clausewitz struggled to describe multidimensional concepts in the language of his times so that his peers could relate to his insights. Even Clausewitz's translators and commentators have been limited in the same way, as they battle over English interpretations of Clausewitz's original German

[9] Carl Von Clausewitz, *On War*, trans. Michael Howard and Peter Paret (Princeton: Princeton University Press, 1984), 89.

[10] Clausewitz, 89.

text. One of the key applications of Clausewitz in modern operational art, the Center of Gravity, is described as "*ein Zentrum der Kraft und Bewegung*", which was translated into English as a "center of all power and movement", and further described as a "hub", implying a two dimensional linear concept akin to a wagon wheel.[11] In this case, the interpretation of the translation may have influenced the way planners conceptualize the center of gravity, shaped by preconceived linear concepts that frame the way Clausewitz is read. This is why many planners seek to define one Center of Gravity at each level of war, imposing a model of the world that is not realistic given the insights of complex systems theory.

Judging by the intentionally multidimensional formulation of his famous trinity, it's very likely that Clausewitz would have greatly benefitted from the insights of complex systems theory. He likely would have found current multidimensional models that consider several variables simultaneously to be much more useful that the two dimensional Hegelian dialectics of his time which only allowed him to compare two variables at a time.[12]

Boyd and adaptation

Perhaps no military theorist seized on the implications of complex adaptive systems as closely as John Boyd, a US Air Force fighter pilot who literally wrote the book on modern aerial combat, and later took his insights to propose more general theories of war in a series of informal written abstracts and presentations.[13] John Boyd also saw the world as

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[11] Joseph L. Strange and Richard Iron, "Center of Gravity: What Clausewitz Really Meant," *Joint Force Quarterly*, no. 35 (Summer 2003): 23.

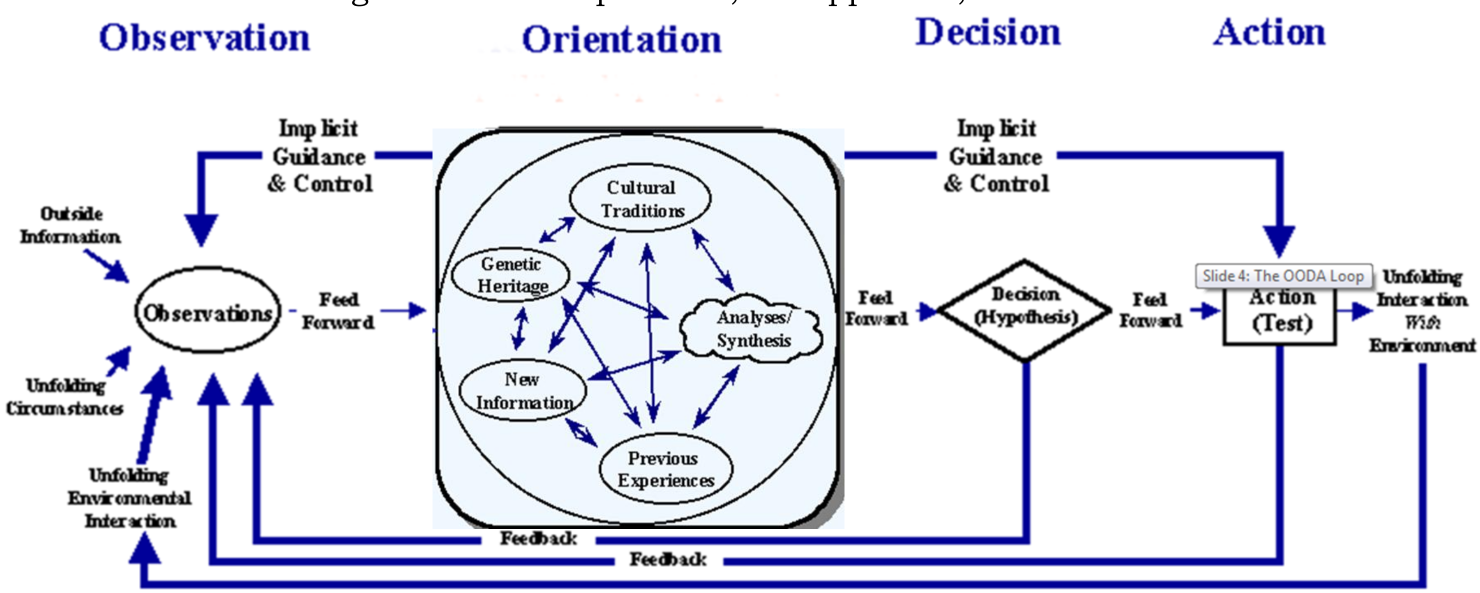
[12] Jamshid Gharajedaghi, *Systems Thinking: Managing Chaos and Complexity* (United States of America: Elsevier, Inc, 2006), 38-42.

[13] Capt. John Boyd, USAF, "Aerial Attack Study" (Nellis AFB: United States Air Force, 1964, photocopied).

a series of interactions between adaptive systems, describing "the nitty gritty" reality of a world that is "uncertain, everchanging, unpredictable", admonishing that "There is no way out… That's the way it is guys. Sorry."[14] His method for conceptualizing this adaptation is popularly known as the OODA loop, a model whose merits are described by Colin S. Gray in *Modern Strategy*:

> The OODA loop may appear too humble to merit categorization as a grand theory, but that is what it is. It has elegant simplicity, an extensive domain of applicability, and contains a high quality of insight about strategic essentials, such that its author well merits honorable mention as an outstanding general theorist of strategy."[15]

The OODA loop is really an open system that allows for continuous reframing of one's concept of self, the opponent, and the environment:



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[14] John Boyd, "The Conceptual Spiral," speech delivered to Air University Students and Faculty, Air University, Maxwell AFB, AL, video http://www.youtube.com/watch?v=qh0k9kc3EY0&feature=related/ , (accessed 16 April, 2010).

[15] Colin S. Gray, *Modern Strategy* (New York: Oxford University Press, 1999), 91.

[16] John Boyd, presentation, *The Essence of Winning and Losing*, Jan 1996.

According to Boyd, “The most important part of that OODA loop is the orientation. It’s the driver, it’s the Schwerpunkt, it’s the key.”[17] In Boyd’s formulation, the only way to survive as an actor in competition with other adaptive actors in a complex, often chaotic environment was not only to *react* faster than one’s opponents, but to *adapt* one’s mental model of the world faster as well. As analyzed by Antoine Bousquet in *The Scientific Way of War*, Boyd’s concept is not merely a cybernetic loop, but rather a model of an adaptive organism,

> “Indeed it is crucial to note that when Boyd talks about a ‘quicker OODA ‘loop”, he does not simply mean cycling through the sequence of observation-orientation-decision-action faster but rather is referring to all cross-referencing connections that make OODA into a complex adaptive system.” [18]

Thus, for Boyd, the crucial function of his “Conceptual Spiral” and included OODA loop is the capacity of an adaptive system or individual for “Destruction and Creation,” in other words, the ability to reject outdated mental models of the world, and replace them with better ones to drive your reactions to both a resisting opponent and an ever changing environment.[19] In Boyd’s own words, “You have to learn how to unlearn too. People who can’t unlearn, we call them dinosaurs, because they can’t relearn…The Conceptual spiral… is a paradigm for survival and growth…The name of the game is to survive and grow.”[20] According to

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[17] John Boyd, "The Conceptual Spiral," speech delivered to Air University Students and Faculty, Air University, Maxwell AFB, AL, video http://www.youtube.com/watch?v=dCAQqT2JvZ4&feature=related/ , (accessed 16 April, 2010).

[18] Antoine Bousquet, *The Scientific Way of Warfare: Order and Chaos on the Battlefields of Modernity* (New York: Columbia University Press, 2009), 195.

[19] John Boyd, "Destruction and Creation" (Unpublished Abstract: 1976, typed).

[20] John Boyd, "The Conceptual Spiral” "http://www.youtube.com/watch?v=dCAQqT2JvZ4&feature=related

Boyd, OODA is a "development loop", not a decision loop.[21] This assertion is perhaps best explained by Bousquet:

> A closer look at the diagram of the OODA 'loop' reveals that orientation actually exerts 'implicit guidance and control' over the observation and action phases as well as shaping the decision phase. Furthermore, 'the entire 'loop', (not just orientation) is an ongoing many-sided implicit cross-referencing process of projection, empathy, correlation, and rejection 'in which all elements of the 'loop' are simultaneously active'. In this sense, the OODA 'loop' is not truly a cycle and is presented sequentially only for convenience of exposition (hence the scare quotes around 'loop'). [22]

Thus, Boyd was the first military theorist to talk explicitly about looking at warfare under the lenses of complex adaptive systems, even if the science and terms hadn't caught up with him yet.

1997 USMC *Warfighting* manual

Not coincidentally, the United States Marine Corps, who had brought John Boyd to their war colleges to lecture, were the first to incorporate concepts of complex systems into their doctrine, specifically in 1997's MCDP-1 *Warfighting*,

> War is a complex phenomenon…In reality, each belligerent is not a single, homogeneous will guided by a single intelligence. Instead, each belligerent is a complex system consisting of numerous individual parts… As a result, war is not governed by the actions or decisions of a single individual in any one place but emerges from the collective behavior of all the individual parts in the system interacting locally in response to local conditions and incomplete information.[23]

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[21] John Boyd, "The Conceptual Spiral http://www.youtube.com/watch?v=dCAQqT2JvZ4&feature=related

[22] Antoine Bousquet, *The Scientific Way of Warfare: Order and Chaos on the Battlefields of Modernity* (New York: Columbia University Press, 2009), 188-189.

[23] *MCDP-1 Warfighting*, by General C.C. Krulak, USMC, Commandant, United States Marine Corps (Washington DC: Government Printing Press, 1997), 12-13.

This recognition led the Marine Corps to pursue the decentralized operations for which the current Marine Air Ground Task Force (MAGTF) is designed, with organic ground and air elements ready to respond to local conditions using the local variety of their combined arms forces.

Effects Based Operations, Network Centric Warfare, and Systemic Operational Design (SOD)

As both technology and systems thinking advanced, a number of military planning constructs were developed to try and take advantage of the new tools and insights that were quickly becoming available. One of the first concepts, Effects Based Operations, or EBO, was initially developed by a US Air Force team called Checkmate, led by Colonel John Warden and then Lieutenant Colonel David Deptula.[24] The intent of EBO was to look at the enemy as a system, and seek to determine the root effects that would achieve desired military ends. Using the advantages of technology (specifically airpower), EBO sought the most efficient ways to achieve those ends, and called for parallel kinetic and non-kinetic attacks against key nodes within that system, disabling it and paralyzing the enemy's ability to react.[25] This way of thinking became the intellectual underpinnings of the 1991 air campaign opening Operation Desert Storm, the stunning success of which seemed to validate the thinking of the concept behind it. In truth, EBO does work very well against tightly coupled, linear systems, and continues to be a valid planning construct for military action, especially air attack. But partly due to the exuberance over the "big win" in Iraq (1991) and the "ugly" yet ultimately successful NATO air effort in Kosovo (1999), many in the

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[24] Paul Van Riper, Lt Gen (ret), USMC, "EBO: There Was No Baby in the Bathwater," *Joint Force Quarterly*, no. 52 (First Quarter 2009): 82.

[25] David A. Deptula, Brig. Gen, USAF. *Effects Based Operations: Change in the Nature of Warfare* (Arlington: Aerospace Education Foundation, Defense and Airpower Series, 2001), Aerospace Education Foundation.

defense community decided that the solution to the problems of attritional warfare that lost Vietnam had finally been found, and that the EBO methodology could be universally applied to war writ large and guarantee victory.

In late 2000, a joint concept of EBO was formulated by US Joint Forces Command J9, based on “operational net assessment” or ONA , developing mechanistic “system of systems analysis” or SoSA techniques of analyzing systems reminiscent of those used in the Vietnam era.[26] In August 2008, General James N. Mattis, the Commander of US Joint Forces Command, determined that this methodology was inherently flawed for operations in complex environments aside from targeting its linear aspects. General Mattis issued a “cease and desist” directive for EBO and its associated ONA and SoSA, stating that “The underlying principles associated with EBO, ONA, and SoSA are fundamentally flawed and must be removed from our lexicon, training, and operations.”[27]

EBO was not the only notable attempt at making systems thinking the centerpiece of a theory of warfare. Inspired by EBO, Network Centric Warfare, or NCW, was a concept advocated by retired admiral A.K. Cebrowski while serving as the Director of the Office of Force Transformation in 2005.[28] The principle underlying the concept was that humans existed in a larger system of technologically linked informational

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[26] Paul Van Riper, Lt Gen (ret), USMC, "EBO: There Was No Baby in the Bathwater," *Joint Force Quarterly*, no. 52 (First Quarter 2009): 83.

[27] James Mattis, General, USMC, Commander US Joint Forces Command, to US Jont Forces Command, August 14, 2008, “USJFCOM Commander's Guidance for Effects Based Operations”, Norfolk, VA.

[28] *The Implementation of Network Centric Warfare*, by Arthur K. Cebrowski, Director, Office of Force Transformation, Department of Defense (Washington DC: Govenment Printing Office, 2005).

networks, which controlled the ability of humans and human organizations to sense, act, and react. As it was described by Cebrowksi,

> NCW is characterized by the ability of geographically dispersed forces to attain a high level of shared battlespace awareness that is exploited to achieve strategic, operational, and tactical objectives in accordance with the commander's intent. This linking of people, platforms, weapons, sensors, and decision aids into a single network creates a whole that is clearly greater than the sum of its parts. The results are networked forces that operate with increased speed and synchronization and are capable of achieving massed effects, in many situations, without the physical massing of forces required in the past.[29]

NCW adopted the systems approach of EBO, and sought to combine it with the OODA loop concepts of Boyd, with the idea that if one had a superior network of interlinked humans, computers, and weapons, one could achieve "option dominance", using superior situational awareness to adapt faster, and in ways that the enemy could not match.[30]

Advocacy for NCW diminished greatly after 2005 due to three primary reasons: the November 2005 death of Cebrowski, the rising insurgency in Iraq for which NCW offered no solutions, and the November 2006 firing of Secretary of Defense Donald Rumsfeld, who had supported the concept under the auspices of Transformation.

Systemic Operational Design, or SOD, also emerged from the shadows of EBO, but unlike NCW which took EBO as a basic assumption, SOD attempted to take the concepts of EBO a step further. The brainchild of retired Israeli brigadier general Simon Naveh and Israel's Operational Theory Research Institute (OTRI), SOD went further than EBO in that it acknowledged there were adaptive aspects of the

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[29] *The Implementation of Network Centric Warfare*, Arthur K. Cebrowski, Director, Office of Force Transformation, Department of Defense (Washington DC: Govenment Printing Office, 2005), i-ii.

[30] *The Implementation of Network Centric Warfare*, 9.

operational environment that could not be predicted or targeted systemically. Based in the roots of general systems theory, SOD stresses "the concepts of co-evolution and competition between existing systems in a search for relative and comparative dominance", and "concentrates on action theory where beliefs and desires as well as intentions better represent the real world."[31] Where EBO was focused on how to affect the system to advantage, and NCW primarily wanted to do EBO faster, SOD wanted to know *why* the system worked, including why people made decisions as their environment changed around them. SOD was first applied in combat in the 2006 war against Hezbollah in Lebanon, with unsatisfactory results when the methodology proved too intellectually cumbersome for field commanders to implement, and actions failed to produce the intended results. [32]

The shortfalls of EBO, NCW, and SOD were not that they were systems based; the problem was that they weren't complex systems based. Each correctly addressed the fact that the operational environment, the enemy, and the joint force all exist as systems. EBO in its original formulation adequately addressed dealing with relatively closed or linear systems, but offered fewer solutions for the nonlinear elements. The joint manifestation of EBO incorrectly assumed that nonlinear interactions could be sensed and understood with linear processes, developing complicated methodologies that were not connected with cause and effect in the real world. NCW made the same

[31] US Army Lieutenant Colonel William T. Sorrells, Lieutenant Colonel Glen R. Downing, USAF, Major Paul J. Blakesley, British Army,Major David W. Pendall, US Army, Major Jason K. Walk, Australian Army, Major Richard D. Wallwork, British Army, "Systemic Operational Design: An Introduction" (Monograph, School of Advanced Military Studies, Ft. Leavenworth, KS, 2005), 12.

[32] Carl Osgood, "Behavior Modification is No Strategy for War," *Executive Intelligence Review*, July 18, 2008, 53.

assumptions as EBO, but overemphasized the speed of the *decision* loop, rather than the speed of the *adaptation* loop, missing Boyd's most significant insight. With SOD, the approach was closer to the holistic approach needed to understand and react in a complex system, and iots concepts may still yield fruitful concepts for future use. But the unwieldiness of the current SOD constructs, compared to the ability of field commanders to grasp how those concepts might be practically applied, introduced an entirely new level of complexity to the battlefield in actual practice. Because of this, in 2006 the Israeli Defense Forces had to grapple with the structural complexity of their own SOD methodology, in addition to the inherent dynamic complexity of fighting a non-state actor amongst the population of a neighboring sovereign state.

The US Army/USMC Counterinsurgency Manual

One of the fundamental assumptions behind US military planning after Vietnam was that a military force deigned to win major conventional wars against a peer competitors like the Soviet Union could also be used to win smaller ones against less sophisticated opponents. The US led coalition's experiences in Iraq between 2003 and 2005 proved that this was not necessarily the case. Forces that had been trained to deal with highly complicated, large scale force on force engagements now found themselves engaged in lower scale, highly complex combat operations amongst populations of civilians which often required them to abandon their legacy equipment and tactics completely. Recognizing the need not only for more adaptive tactics, but more adaptive ways of thinking, in 2006 the US Army and US Marine Corps collaborated on a new counterinsurgency field manual.[33]

[33] *FM 3-24/MCWP 3-33.5 Counterinsurgency*, by USA LTG David Petraeus and LTG James F. Amos, USMC, Commander, US Army Combined Arms Center, and Deputy Commandant, Combat Development and Integration (Washington DC: Government Printing Office, 2006).

With the entering argument that "Insurgency and counterinsurgency (COIN) are complex subsets of warfare", the new manual sought to help Soldiers and Marines understand the fundamental difference between the large scale/less complex major combat operations they had been trained for, and the small scale/high complexity combat operations that they were engaged in.[34] It was also notable in that it was the first field manual to introduce the concept of *campaign design*, a methodology introduced by the Marines meant to be used in complex battlefields to "achieve a greater understanding, a proposed solution based on that understanding, and a means to learn and adapt."[35] The Counterinsurgency Field Manual was the first notable attempt since the 1997 USMC Warfighting Manual to propose specific applications of complex systems theory to warfighting, continuing in the tradition of their mentor, John Boyd. The Counterinsurgency Manual brought the concepts of complex systems theory into mainstream discussions in Army and Marine Corps headquarters, and spurred the next step in operational design: the Design movement currently underway in the US Army, which has also been adopted for examination by US Joint Forces Command.

Design

Spurred mostly by the failure of legacy planning processes to help senior leaders anticipate and adapt to the complex and often chaotic environments of post 9-11 Afghanistan and Iraq, the US Army Combined Arms Center and its School of Advanced Military Studies (SAMS) are currently advocating for a new planning methodology called Design, with

[34] *FM 3-24/MCWP 3-33.5 Counterinsurgency*, by USA LTG David Petraeus and LTG James F. Amos, USMC, Commander, US Army Combined Arms Center, and Deputy Commandant, Combat Development and Integration (Washington DC: Government Printing Office, 2006), 1-1.

[35] *FM 3-24/MCWP 3-33.5 Counterinsurgency*, 4-1.

the goal of promoting a more holistic approach to framing both operational problems and solutions than previous planning processes could offer. Described in the latest version of US Army Field Manual 5-0, Design borrows from complexity and systems theories to propose a new approach to informing military planning processes such as the Joint Operational Planning Process (JOPP) and Military Decision Making Process (MDMP). In a recent *Military Review* article, Brigadier General Cardon of the US Army Combined Arms Center described the imperative to inject Design into legacy planning processes:

> Although our Military Decision Making Process (MDMP) remains an indispensable model for the problems posed by a bipolar security environment, it fails to provide the advanced cognitive tools necessary to solve the complex, ill-structured problems common to contemporary operations. The introduction of *design* in FM 5-0 addresses that gap in our doctrine, while providing a sound approach to address the challenges inherent to 21st-century conflict."[36]

Design, as defined in FM 5-0, is "a methodology for applying critical and creative thinking to understand, visualize, and describe complex, ill-structured problems and develop approaches to solve them."[37] The name and the concept is derived from civilian applications of project design, and is considered by systems theorists to be the latest major phase of operations thinking, eclipsing prior ops research and cybernetics/open systems methodologies.[38] Although the term design is often used interchangeably to describe both a process, strategies derived

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[36] Edward C. Cardon, Brigadier General (P), U.S. Army, and Lieutenant Colonel Steve Leonard, U.S. Army, "Unleashing Design: Planning and the Art of Battle Command," *Military Review* (March/April 2010): 2.

[37] *Field Manual 5-0: The Operations Process*, by General Martin E. Dempsey, Commanding General, TRADOC (Washington DC: Department of the Army, 2010), 3-1.

[38] Jamshid Gharajedaghi, *Systems Thinking* (United States of America: Elsevier, Inc, 2006), 16.

from that process, and products resulting from the process, the developers of US Army Design have adopted the following description:

> "America's International Technology Education Association defines design as an iterative decision-making process that produces plans by which resources are converted into products or systems that meet human needs and wants or solve problems. According to this definition, design is iterative, meaning it does not follow a linear sequence, and it does not terminate just because a solution has been developed. Because design can be used to produce systems, not just products, and is applicable to the spectrum of human needs and wants, design is both extremely general and ubiquitous in nature."[39]

At its core, US Army Design and civilian design methodologies seek to understand the complex system of human and nonhuman interactions within the environment, and use this insight to apply military force (or the threat of force) to physical and moral points of leverage, "nudging" the system towards favorable directions and outcomes. As described by Jamshid Gharajedaghi in *Systems Thinking*, "Designers seek to choose rather than predict the future, producing a design that satisfies a multitude of rational, emotional, and cultural dimensions."[40] Thus, Design is about producing outcomes, not merely understanding how the system works.

Recognizing that there are limits to the ability of single individuals to step out of their own backgrounds and biases to look at problems from a holistic perspective, Design practitioners attempt to harness the "power of the team mind" to create better understanding of the systems they operate within. As described by Gary Klein in *Sources of Power: How People Make Decisions,"*This is the power of the team mind: to create new

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[39] Col Stephan J. Banach and Dr. Alex D. Ryan, "The Art of Design: A Design Methodology," *Military Review* (March-April 2009): 105.

[40] Jamshid Gharajedaghi, *Systems Thinking* (United States of America: Elsevier, Inc, 2006), 23.

and unexpected solutions, options, and interpretations, drawing on the experience of all the team members to generate products that are beyond the capabilities of any of the individuals."[41] Army commanders practicing Design assign three distinct, small groups of individuals from different backgrounds to simultaneously look at the problem, the operational environment, and at possible solutions, as shown in this diagram from FM 5-0:

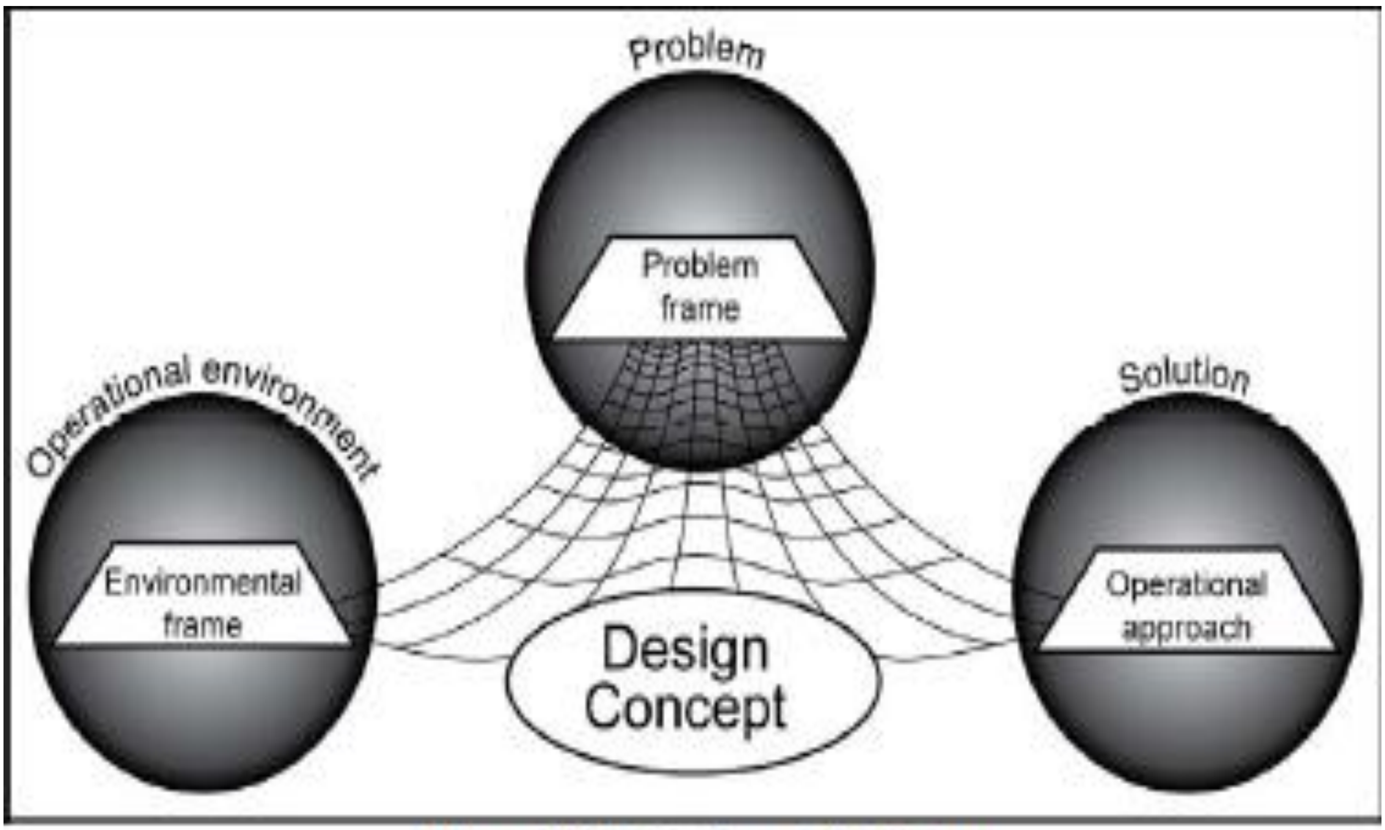

Figure 3-1. The design methodology

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[41] Gary Klein, *Sources of Power: How People Make Decisions* (Cambridge: MIT Press, 1999), 245.

[42] *Field Manual 5-0: The Operations Process*, by General Martin E. Dempsey, Commanding General, TRADOC (Washington DC: Department of the Army, 2010), 3-7.

The Army Design concept is an attempt to in effect create a collective consciousness in the planning team that simultaneously looks at both the parts of the system and their relationships. In contrast, the analytical methodologies of JOPP and MDMP emphasize breaking up the whole of the system into understandable parts, but fail to emphasize recombining the understanding of parts back into a synthesis that considers the whole. Design is also intended to be an unending iterative process that stresses the most accurate initial understanding of the problem on the first iteration, known as "problem framing," and then continually "reframing" the problem as the complex system adapts to both your actions and external stimuli.[43] Only by doing this can solutions be matched to the actual state of the environment, increasing the probability that the solutions actually address the root problems, and decreasing the chance that solutions create unforeseen, undesirable side effects that go beyond acceptable risk.

Looking at the problem, environment, and solutions separately and simultaneously in Design is an application of complexity and systems theories, which propose that understanding comes not only from examining the parts of the system individually, but also in observing the emergent qualities of the whole. Design presupposes that "seeing the whole requires understanding structure, function, and process at the same time" is essential, and requires constant iteration to deal with the unpredictability of the complex adaptive systems interacting in the operational environment.[44] While it may not be the true solution to our quest to harness complexity in planning, it's definitely a step in the right direction in its recognition of the nature of the challenge.

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[43] Col Stephan J. Banach and Dr. Alex D. Ryan, "The Art of Design: A Design Methodology," *Military Review* (March-April 2009): 107.

[44] Jamshid Gharajedaghi, *Systems Thinking* (United States of America: Elsevier, Inc, 2006), 110.

Other Military Explorations of Complex Systems Theory

As Thomas S. Kuhn described in his book *The Structure of Scientific Revolutions*, the institutional adoption of new paradigms is seldom an overnight affair, nor does it usually occur at a steady pace.[45] Behind many of the movements described previously were various other works that spurred military thinkers to incorporate complexity theory and systems theory into their examinations of military concepts.

Even before the rise of complexity theory, Colonel John M. Etchemendy described complexity as "The Demon of Defense", as his 1957 Air War College thesis detailed the problems of managing high technology platforms.[46] In 1992, Alan Beyerchen wrote an article for *International Security* called "Clausewitz, Nonlinearity, and the Unpredictability of War" which examined Clausewitz's *On War* using scientific concepts of nonlinearity.[47] One of the first significant examinations of warfare under the lens of the new sciences is Andrew Ilachinski's 1996 study for the Center for Naval Analysis, which examined the applicability nonlinear dynamic and complex systems theory to land warfare.[48] At the same time, numerous student authors

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[45] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago, 1996).

[46] Col John M. Etchemendy, USAF, "Complexity — The Demon of Defense" (PhD diss., Air University, Maxwell AFB, AL), 1957.

[47] Alan Beyerchen, "Clausewitz, Nonlinearity, and the Unpredictability of War," *International Security* Vol 17, no. 3 (Winter 1992-1993): .

[48] Andrew Ilachinski, *Land Warfare and Complexity, Part II: An Assessment of the Apliccability of Nonlinear Dynamic and Complex Systems Theory to the Study of Land Warfare (U)* (Alexandria: Canter for Naval Analysis), Center for Naval Analysis, CRM 96-68.

tried to look at how concepts like chaos theory could be used for military applications.[49]

The Department of Defense's Command and Control Research Program (CCRP) took on the study of complex systems several times starting in the late 90s, with varying degrees of success. One of the most notable contributions was Tom Czerwinski's *Coping With the Bounds,* originally released in 1998, but reissued as a Neo-Clausewitzian primer in September 2008.[50] Czerwinski's book was one of the first to attempt to use complex systems theories to try to reconcile classical prescriptive and descriptive military theories. CCRP also published a series of books that attempted to use complex systems theories to make arguments for effects based operations and network centric operations, which yielded some useful insights into command and control for complex operations, but were generally not accepted by the military community do to their overemphasis on command and control information sharing networks vice more general human systems. [51]

While there are many books currently proposing applications of complex systems theory for business and economics, there are few major work outside of CCRP publications currently dedicated to military

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[49] CDR Tony Laird, USN, "Complexity and Military Strategic Thought; Balancing Order and Chaos" (PhD diss., National Defense University, Washington DC, District of Columbia), 1996; John Gore, "Chaos, Complexity, and the Military" (PhD diss., National Defense University, Washington DC, District of Columbia), 1996.

[50] Thomas J. Czerwinski, *Coping With the Bounds: A Neo Clausewitzian Primer* (Washington DC: DoD Command and Control Research Program, 2008).

[51] James Moffatt, *Complexity Theory and Network Centric Warfare* (Washington DC: DoD Command and Control Research Program, Information Age Transformation Series, 2003), CCRP; Edward A. Smith, *Complexity, Networking, and Effects Based Approaches to Operations* (Washington DC: Dod Command and Control Research Program, The Future of Command and Control, 2006), CCRP; David S. Albers and Richard E.Hayes, *Planning: Complex Endeavors* (Washington DC: DoD Command and Control Research Program, The Future of Command and Control, 2007), CCRP.

applications of complex systems theory. The most prominent example is perhaps Antoine Bousquet's *The Scientific Way of Warfare*, which surveys how scientific progress has influenced military theory and doctrine.[52] Yaneer Bar Yam includes a chapter on "Military Warfare and Conflict" in 2004's *Making Things Work: Solving Complex Problems in a Complex World*.[53] The most direct treatment of complex systems theory related to military strategy can be found in two chapters of Dr. Everett Dolman's *Pure Strategy,* which includes discussions of chaos, complexity, emergence, and adaptation related to warfare.[54] With the increase visibility that recent discussions on NCW, EBO, the Counterinsurgency Manual, SOD, and Design, students of the war colleges are increasingly writing their monographs and theses on complex systems topics, especially at the US Army School of Advanced Military Studies.[55]

There are also relatively few major works that applying complex systems theory specifically to airpower. In 2004, Doug Norman advocated that looking at Air Operations Centers as complex adaptive systems would lead to better methods of designing and maintaining them than the current top down attempts to standardize those processes

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[52] Antoine Bousquet, *The Scientific Way of Warfare: Order and Chaos on the Battlefields of Modernity* (New York: Columbia University Press, 2009).

[53] Yaneer Bar-Yam, *Making Things Work: Solving Complex Problems in a Complex World* (United States of America: NECSI Knowledge Press, 2004).

[54] Everett Carl Dolman, *Pure Strategy* (New York: Frank Cass, 2005).

[55] MAJ John T. Calhoun, USA, "Complexity and Innovation:Army Transformation and the Reality of War" (Monograph., School of Advanced Military Studies, Ft. Leavenworth, KS), 2004; MAJ David P. McHenry, USA, "Battle Command: An Approach to Wickedness" (MMAS Monograph, School of Advanced Military Studies, Ft. Leavenworth, KS), 2009; MAJ Bill A. Papanastasiou, USA, "More Than Just Plan, Prepare, Execute, and Assess: Enhancing the Operations Process by Integrating the Design and Effects-Based Approaches" (MMAS Monograph, School of Advanced Military Studies, Ft. Leavenworth, KS), 2009.

allowed.[56] In 2005 Dr. Scott Gorman wrote about the implications of nonlinearity in the development of airpower, and cautioned against contemporary attempts to eliminate battlefield uncertainty with technological solutions, which becomes an inherently unfeasible proposition when one understands the full implications of nonlinearity.[57] Col Michael Kometer's *Command in Air War: Centralized vs. Decentralized Control of Combat Airpower* uses systems theory to compare the tradeoffs between distributing control of airpower at different levels of scale depending on how tightly coupled the operation is (referencing Perrow), and is one of the first to address issues of complexity vs. scale in balancing theater vs. local requirements for air support under the CFACC construct.[58] Outside of these works, Air Force interest in complex systems theory has lagged that of the other services, with few student papers directly addressing the implications of the new sciences to airpower applications, and few organizations requesting related studies in the AURIMS database of suggested research topics given to Air University students as suggested points of departure for their student papers.

The Next Step

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[56] Doug Norman, *Engineering a Complex System:: a Study of the Air & Space Operations Center (AOC)* (Boston: International Conference on Complex Systems, 2004), Powerpoint Presentation, http://rds.yahoo.com/_ylt=A0geuy6vmvlLlVYAAkRXNyoA;_ylu=X3oDMTEyOHRpcGJrBHNlYwNzcgRwb3MDMwRjb2xvA2FjMgR2dGlkA0Y4NjJfODg-/SIG=127lrbkft/EXP=1274735663/**http%3a//sdm.mit.edu/conf05/Presentations/dnorman.ppt.

[57] G. Scott Gorman, "Seekng Clocks in the Clouds: Nonlinearity and American Precision Airpower" (PhD diss., Johns Hopkins University, Baltimore, MD), 2006.

[58] Col Michael W. Kometer, USAF, *Command in Air War: Centralized vs. Decentralized Control of Combat Airpower* (Maxwell AFB: Air University Press, 2007).

Admittedly, there is currently no perfect solution to guarantee true holistic understanding of any complex system, nor is it likely there will ever be combination of descriptive or prescriptive theories that can ever hope to completely dissipate the "fog and friction" of war, as our examination of Ashby's Law of Requisite Variety suggests. But the recent advances in intellectual inquiry in complex systems theory, and the military's honest albeit imperfect attempts to embrace these concepts, is encouraging, even if it comes late compared with the vast sweep of military history. Despite the fact that our current tools are imperfect, and the next set will be imperfect as well, we are still developing theories and tools that better match the reality of human experience within which war exists as an emergent phenomenon. Even if our methods of inquiry still aren't close to matching the complexity of reality, we are slowly but surely getting closer to it.

The good news is that complex systems theory does indeed help to bolster the military theories that have resonated with generations of military thinkers, giving us new insights into why these ideas indeed seem to be timeless. As more and more military thinkers become familiar with complex systems concepts, and relate the new ideas to the old ones, there is a much better chance of larger organizational acceptance of intellectual models that better approximate war as it really is, reducing surprise even when it cannot eliminate uncertainty.

Chapter 5

Complex Systems Theory Applied to Joint Airpower

Airpower always operates within the context of complex adaptive systems – the word airpower itself implies an emergent property that exists only during a sustained interaction of people, machines, communications networks, and the physical and psychological modifications that airpower assets can make on the environment. If "flexibility" is indeed "the key to airpower," as the popular aphorism among Airmen proclaims, then the key to that nonlinear flexibility is a stable linear underpinning of basing, logistical support, and command and control processes embodied in the Air Tasking Order, the base plan that airpower deviates from in order to respond to emergent situations during execution. Due to the reach and speed of airpower, and the multiple roles and capabilities of individual air assets, the number of possible outcomes from even a single day's missions is exponential, simultaneously spanning various levels of scale and complexity. Because of this complexity, and our lack of adequate intellectual concepts and language to describe it, both airpower advocates and critics have often had a difficult time expressing their views about the use and abuse of airpower in the context of joint operations. The language of Complex Systems provides better tools to understand these complexities, and can help us to better focus in on the key tradeoffs we must consider, and risks we must assume across various levels of scale, when determining how airpower can best assist joint force commanders in achieving their goals.

As in other complex endeavors, practitioners of airpower have been dealing with its complexity long before the complex systems concepts were available to explain many of them, and as a result, there are still significant challenges in understanding and advocating the best ways to present airpower to the joint force, or to balance the effectiveness vs. the efficiency of airpower across various levels of scale and complexity. To understand how complex systems theory can do this, we must review how airpower is presented to and used by the joint force. We will then review some of the key points of contention between Airmen and their joint partners, and describe how complex systems concepts can help us to reconcile them.

Key Concepts of Joint Airpower Integration

The integration of airpower continues to bedevil the joint force even after almost twenty years of continuous combat operations in Southwest Asia. Since Operation Desert Shield in 1990, US Air Force officers have served US Central Command (CENTCOM) as the Combined Forces Air Component Commander (CFACC), and have been the driving force behind the Theater CFACC concept by which one senior airman, supported by a jointly manned Combined Air Operations Center (CAOC), consolidates all theater level air and space operational planning and execution for the Combatant Commander (COCOM). This centralized command and control construct has been criticized by some in the joint community, and some in the Air Force itself, as being ill adapted to supporting highly decentralized irregular warfare efforts in places like Iraq, Afghanistan, and the Horn of Africa.

The CFACC concept was originally designed to unify command and control of joint airpower for the Theater Commander in Chief (CINC), a regional warfighting position now referred to as a Combatant Commander, which was created by the 1986 Goldwater Nichols Act in order to correct harmful interservice discontinuities in command and

control such as those experienced in Lebanon, Grenada, Libya, and Panama.[1] Developed and promoted primarily by the Air Force, the CFACC concept with its associated Air Operations Center (AOC) and Air Tasking Order (ATO-) came into prominence during 1991's Operation Desert Storm largely because these were the only command and control tools available at the time that could handle the complex logistics of coordinating the thousands of daily sorties the coalition effort required. Before Desert Storm, there was still considerable disagreement among the services about how centrally airpower should be controlled. This tension was reflected in the 1986 Omnibus Agreement which confirmed that direct support of the Marine Air Ground Task Force (MAGTF) was the primary mission of Marine Corps air assets, but still did not resolve differences of opinion between Marine and Air Force differing interpretations of the last C in CFACC as "coordinator" and commander" respectively.[2] Similarly, it did not include provisions for Army aviation to be listed in the Air Tasking Order, protecting Army control of its organic rotary and fixed wing assets.[3] As air operations continued after the conclusion of Desert Storm, the Air Force CFACC remained in place to handle the continuing requirements of enforcing the Northern and Southern Watch "No Fly Zone" in Operations in Iraq, and also served to coordinate later combat air operations in Bosnia, Kosovo, Sudan, Afghanistan, and Iraq.

In the wake of the 9-11 attacks of 2001, and the subsequent US led invasions of Afghanistan and Iraq, it became clear that CENTCOM's

[1] James A. Winnefeld and Dana J. Johnson, *Joint Air Operations: Pursuit of Unity in Command and Control 1942-1991* (Annapolis: Naval University Press, 1993), 100.

[2] James A. Winnefeld and Dana J. Johnson, *Joint Air Operations: Pursuit of Unity in Command and Control 1942-1991* (Annapolis: Naval University Press, 1993), 101.

[3] Winnefeld and Johnson, 101.

air component would be required to support multiple, geographically separated contingency operations simultaneously, as well as various joint task forces within the same contiguous Area of Operations (AOR). Although their area of operations remained mostly peaceful, air planners in the Pacific also realized that should any conflict erupt in the Pacific Command (PACOM), there would be significant challenges in prioritizing and distributing limited air assets between the various supported commands who would likely be requesting the same air assets and capabilities simultaneously. Realizing that the decision to prioritize theater priority and weight of effort remained with the combatant commander acting as the theater level Joint Force Commander, the Air Force developed the Warfighting Headquarters (WFHQ). This Air Force organization was designed to serve as the nucleus for a joint air component command staff that would provide the theater a single joint headquarters, an Air and Space Operations Center (AOC), to manage all theater joint airpower requirements. Since most of the limited Air Force service component assets would have to be shared between the various supported commanders within the same AOR, the Air Force Component, or AFFOR, was also presented to the combatant commander at the theater level, rather than presenting separate AFFORs to various individual subordinate commanders.

With the implementation of the Air Force C2 Enabling Concept, the Warfighting Headquarters evolved into the Component Numbered Air Force (NAF), which is currently the Air Force's senior warfighting unit.[4] Specifically designed to serve in the role of the Theater CFACC, the Component NAF continuously operates an AOC, and forms the nucleus

[4] *Air Force Forces Command and Control Enabling Concept (Change 2),* by Gen T. Michael Moseley, US Air Force Chief of Staff (Washington DC: Government Printing Office, 2005).

of a joint air component headquarters for the CFACC designated by the COCOM who is serving in the role of Theater Joint Force Commander.

The design of the Component NAF, AOC, and Theater CFACC construct reflects some central assumptions that the Air Force makes about the capabilities it must provide to the COCOM as a faithful and diligent subordinate command ready to assume CFACC responsibilities if tasked. These include:

- The air component must be able to handle the requirements to support several geographically separated contingency operations simultaneously
- In large scale combat operations, air component assets and personnel will be insufficient to provide each lower echelon ground commander with their own complete AFFOR and AOC, therefore central management is required to flex these forces among various supported commands and components in accordance with continuously changing COCOM theater priorities
- The air component headquarters must maintain the capability to handle operations along the entire range of military operations, and must maintain the ability to rapidly transition to major combat operations at any time in order to deter or defeat regional aggression
- The air component headquarters must have the ability to coordinate with functional COCOMs outside of the theater to coordinate intertheater movement, reachback support, and coalition/joint liaison
- The air component headquarters must develop and maintain the decision and execution support tools to enable the theater commander to understand the air component capabilities,

prioritize its use, direct its execution, and assess its effectiveness

- The air component must be located where it can minimize the impact of frequently changing security, force protection, communications, liaison, and configuration requirements

Thus, the assumptions presented above reflect the reasons for some of the physical characteristics for which the Air Force command and control is often criticized, including a large personnel footprint, complex battle rhythms, and physical distance from the battlefield. The Theater CFACC construct and supporting infrastructure is designed to support the COCOM's full range of responsibilities, all the way from Major Combat Operations to Stability and Support Operations. In other words, the theater CFACC construct is optimally designed to provide support for what the COCOM *is continually responsible for*, not necessarily for what it is doing *at the moment*. The primary focus of the air component, inferred from the way they have structured their organizations, is maintaining the capability to deter and win large scale combat operations. One of the underlying assumptions of this approach is that the constructs that can handle large scale operations can also scale down for smaller ones, and this leads to the points of contention between centralization and decentralization of airpower.

Criticisms of the Theater CFACC Construct

The primary criticism of the air component by the other components is that the air component is not responsive enough to their immediate needs for support, mostly due to the physical separation of the CFACC from the various supported commanders in the ground components. Despite the availability of numerous collaborative tools, the commonly heard sentiment that "Virtual Presence means Actual Absence" reflects a common mindset among the supported commanders that a geographically distant CFACC cannot appreciate the local

situation or requirements for air support. There are several possible reasons that members of the ground component may feel this way:

- Modern communications technology has not replaced the ability of close physical contact to facilitate the formation of personal relationships and trust that are crucial for loosely coupled systems to operate. This is not a foreign concept to Airmen, as it is also the reason that Air Force Expeditionary Task Forces attempt to train and fight together, and also why individual tactical units attempt to fly the same crewmembers together in combat.
- It is natural to focus on your area of responsibility, and local bias makes it difficult for local commanders in distributed operations to detach emotionally when competing for support with adjacent units. Local bias also means that there is a natural tendency for people to assume that their local experience is true of the wider situation. Thus, those who have a negative experience with the air component during a significant emotional event may tend to disparage the air component overall.
- The converse of the previous point is also true, and at times "out of sight" is indeed "out of mind". If trust and personal relationships have not been formed, and liaison has not been created where it is needed, the needs of the distant supported unit may not be understood or correctly prioritized among various competing requirements at higher headquarters

In the specific case of the Theater CFACC in CENTCOM, there are several local conditions that cause some to question the effectiveness of the Theater CFACC concept. These include:

- Joint doctrine implies that each subordinate joint force commander can be assigned its own AFFOR and Air

Expeditionary Task Force, but AFCENT supplies an AFFOR only to the COCOM, contributing to the perception that Air Force officers supporting subordinate commands like MNF-I and ISAF don't "work" for that commander

- There is a perception that the CAOC is more of a US Air Force headquarters than an integrated coalition/joint headquarters. This perception may pervade because the Air Force general officers have continuously served as the CFACC for CENTCOM, and also may be partly due to the fact that few coalition allies have full access to certain parts of the CAOC planning process
- There is currently a lack of operational air planning expertise available to support multiple ground planning efforts. The irregular character of combat in Iraq and Afghanistan has meant that the planning for ground operations has become increasingly decentralized, but air force liaison manning has not kept up with the increased demand for planning expertise and liaison on the ground.
- A perception exists that the Air Force has failed to place a priority on addressing these issues despite numerous RAND and Tiger Team studies since 2001 advocating increased liaison with ground components
- The perception that the Marine Corps system of air command and control, which is located concurrently with the ground commander, provides more rapid and flexible response than the air tasking cycle at the CAOC
- The perception that the CAOC is overly bureaucratic, overmanned, and potentially vulnerable to a "knock-out blow" that would render it totally ineffective
- The perception that the CAOC decides which supported units receive priority, and arbitrarily redirects airpower based on

their view of what's most important rather than the supported ground commander's priorities'

Whether valid or not these perceptions have become reality for many in the joint force, and have caused some to form a cynical view of both the Theater CFACC concept and of the Air Force in general. These are the primary reasons that many — including some in the Air Force — feel that the US Air Force is disconnected or even removed from the joint fight, despite the fact that the Air Force has been conducting combat operations continually in Southwest Asia since 1990.

The US Air Force's Response to Operation Anaconda

2002's Operation Anaconda, the first major engagement of US Army forces in large unit, high intensity combat operations in Afghanistan, highlighted many of these disconnects between the ground and air components.[5] Due to many contributing factors not attributable to any one actor or organization, Operation Anaconda required a sudden, dramatic, and unanticipated increase in the amount of air support the ground component required. This forced the air component to scramble in order to secure the necessary assets, basing, logistics, consumables, planners, equipment, and tactical expertise to support the ground maneuvers in the geographically forbidding Shah-i-kot Valley in Eastern Afghanistan.[6] While there is still no definitive joint consensus on what the key causes for this disconnect between ground and air operations was, both sides agreed that coordination needed improvement.

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[5] Elaine Grossman, "Was Operation Anaconda ill-fated from start?," *Inside the Pentagon*, July 29, 2004, http://www.d-n-i.net/grossman/army_analyst_blames.htm. (accessed 22 March, 2009).

[6] Richard Kugler, *Operation Anaconda in Afghanistan: A Case Study of Adaptation in Battle* (Washington D.C.: Sponsored by the Office of the Deputy Assistant Secretary of Defense Forces Transformation and Resources, February 2007), Center for Technology and National Security Policy, Case Studies in National Security Transformation Number 5, 1.

In the aftermath of Anaconda, the Air Force created the Air Component Coordination Element, or ACCE, as a mechanism to attempt to bridge some of the gaps identified between the operational level air and ground component headquarters.[7] The intent of the ACCE was to improve CFACC visibility into the ground component planning and execution at the operational level, in order to ensure earlier air component involvement in ground component planning processes. With the ACCE serving as the CFACC's "eyes and ears", the CAOC was to have early awareness of the anticipated requirements for air support, and could then anticipate the assets and logistics needed to provide the optimal mix of air capabilities to complement the ground scheme of maneuver, thus preventing the last minute adjustments and shortfalls experienced in Operation Anaconda. Unfortunately, as Operation Medusa in 2006 demonstrated, the ACCE did not solve the challenges of coordinating air and ground actions in Afghanistan.

Anaconda Revisited (Almost?)

In 2006, Operation Medusa was conducted under the command of the NATO International Security Assistance Force (ISAF), in order to clear areas of Eastern and Southern Afghanistan of Taliban infiltration.[8] Planned as a series of several coordinated but decentralized ground sweeping actions, early planning efforts did not identify the need for a significant increase in the supporting air effort. However, about 48 hours prior to the operation kickoff, the requirements for air support nearly doubled overnight. In this case, the air component was able to

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[7] *United States Central Command Air Forces Air Component Coordination Element (ACCE) Concept of Operations (CONOPS)*, by Lt Gen Michael T. Moseley, Commander, CENTAF (Shaw AFB: CENTAF, 2002).

[8] Clint Hinote, Lt Col, USAF, "Centralized Control and Decentralized Execution: A Catchphrase in Crisis?" (Research Paper 2009-1, Air University, Maxwell AFB, AL, 2009), 28.

adjust with the assets in theater, and the effort never reached the complexity and scale of Anaconda, yet the element of surprise regarding sudden increases in air support requests was similar.[9] Despite the fact that an ACCE was assigned, air and ground components were still not communicating adequately to prevent surprises like the sudden requirements for close air support.

Centralized vs. Decentralized Control of Airpower

As a result of these critiques of the current Theater CFACC concept, and also resulting from experiences like Anaconda and Medusa, some Air Force officers have advocated for locally based CFACCs with dedicated assets, directly responsive to the supported ground commanders in places like Iraq and Afghanistan. The benefits of this approach include improved personal relationships between air and ground commanders due to physical proximity, more influence in the theater apportionment process by having a high rank Airmen directly involved in local planning, and additional responsiveness due to having specific air and planning assets assigned to the specific theater. There are also calls for the increasing use of mission type orders rather than executing centralized control from the CAOC, which would theoretically allow for greater decentralization of planning and execution, reducing the need for theater level oversight of air assets. Additionally, liaison with lower echelon units would be increased by increasing the numbers of ALOs assigned, and giving them more in-depth training in joint planning processes.

Some Air Force Officers have also advocated using the model of the Marine Corps Air Ground Team as a model for these decentralized air operations. Under this methodology, air assets are assigned to specific units, and included in planning efforts from the start. In cases where

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[9] Hinote, 30.

there are sufficient assets to assign them to individual commanders, this method could potentially provide the most flexibility to that individual ground commander, assuming minimal coordination for logistical support outside of that area of operations was required. Control of these air assets would be concentrated in the Air Support Operations Group (ASOG) and controlled locally by an Air Support Operations Center (ASOC) rather than the AOC. Additional air liaison elements for airlift and intelligence would be placed in the tactical operations center, providing the local commander with more air expertise right in his own headquarters.

The main idea behind these concepts — closer coordination with the ground component — is entirely appropriate in that it clearly demonstrates a commitment to the joint fight, it pushes planning expertise forward where it is needed in decentralized planning processes, and it increases the ability of ground commanders to secure priority for their requests. But such a change would not come without costs and risks in other areas, ones that are not being adequately understood or considered in current debates between centralized and decentralized control of airpower. This is where Complex Systems Theory can provide valuable insights as to the true nature of the problems of joint airpower integration.

Looking at the Joint Force as a Living Network

Complex systems theory verifies something that the joint force has known intuitively for some time: while teamwork is essential, some degree of separateness is just as important. Having separate services provides the joint force the variety it needs to adapt to a large number of possible contingencies, but using joint criteria for selection in both senior officer promotions and joint acquisition projects creates a strange attractor that keeps the separation from becoming destructive. This creates a truly healthy competition between services competing for

limited budget resources, and preserves core service competencies in niche areas that would otherwise be subsumed by more common concerns due to the phenomena of premature convergence were there only a single armed service. Competition between the services and functional components at lower levels then becomes cooperation at higher levels during the formulation of strategy under the context of a joint task force or combatant command. Having some degree of overlap among the services in various mission areas gives the entire system resilience, making many creative combinations of forces available to achieve the joint force commander's objectives. Joint command and control structures are designed to balance the levels of competition and cooperation among services, facilitate the flows of information and interaction between the services and components, and use intelligence, guidance, measures of performance/effectiveness, and rules of engagement that serve as strange attractors to drive unity of effort towards commonly shared goals. At least, that's the way the joint force operating concepts are designed.

In reality, both the environment and the structures of joint organizations are emergent, constantly adapting. Joint force commanders often inherit legacy command and control agreements and constructs that were not designed with optimization of the current mission in mind, and have to build organizations from these foundations up, rather than impose a more doctrinally harmonious solution from the top down. This was the case in Afghanistan with the NATO Air Task Force in ISAF, originally constructed in Kabul as a scheduling function for air transport aircraft in support of stability operations. As the insurgency grew, the Deputy Commander for Air's small staff, limited assets, and minimal ability to command and control airpower were overwhelmed by the requirement to provide combat support to ground forces, and gradually developed a closer, albeit non-doctrinal association

with the Central Command Combined Air Operations Center. The ACCE was to play a key role in working the coordination between the NATO and US led headquarters, but despite its presence in Afghanistan during Operation Medusa, problems similar to the ones four years earlier in Operation Anaconda were observed. Why? If we analyze the situation with concepts from complex systems theories, the reasons for the current disconnects in the joint planning processes become clearer.

Joint C2 as a Network

If we see the joint and functional component staffs as complex adaptive systems, and liaison elements as hubs that link them, we can use concepts of hub fitness to determine what the proper role for the ACCE should be, and compare that to the way it has operated in practice.

Joint Staffs as Networked Systems

We can look at the ground and air components as separate complex adaptive systems, working as agents in the even larger complex adaptive system of the operational environment. Each is imprinted with a specific set of information, associated with its area of specialization, with which it views a common operational environment, and offers different sources of variety for adaptation. Individual planning cells within each functional component staff remain isolated from each other, preserving that uniqueness that prepares the joint force for later adaptation to unforeseen contingencies, but higher levels of the cells, specifically the planning team leads, collaborate with planning team leads in the other components primarily through telecommunications.

While this is a useful way to balance specialization vs. teamwork, it does not facilitate the richness of variety that occurs from random collisions of disparate agents in both systems – nonverbal cues, happenstance side conversations between scheduled meetings, and chance encounters that provide information the planners could never get

inside their relatively homogenous group of peers. It is these unpredictable associations that form by people doing everyday things together in proximity, and connect them in multiple ways that formal processes cannot hope to achieve. While we may not be conscious of it, it is this process of interaction that builds the trust needed to conduct loosely coupled operations in complex environments, and why commanders from both sides intuitively feel and advocate for "being there" in joint fights, even when more practical assessments of process indicate that more distributed operations are viable or even preferable.

Without personal contact and chance associations, planning between geographically separated staffs tends to be "stovepiped" due to the relative homogeneity of the component staffs, even with occasional cross coordination. Over time, local bias tends to predominate in these separated planning cells, with the air component leaning towards theater level issues, and the ground component leaning towards local ones in areas where ground forces are present, usually emphasizing two completely different levels of complexity and scale. Unless the joint staff very clearly spells out the distinctions between these and defines priority between them, both sides tend to assume that their viewpoint describes the overall operational environment, rather than just one perspective of it. From a systems perspective, a human being traveling between the two staffs is still the richest carrier of information to break both staffs out of their respective local bias, hence the liaison element concept.

Liaison Elements as Highly Connected Hubs

The concept of the liaison element requires that the visiting liaisons are experts in the headquarters that they *represent*, not the ones that they *reside* in. In systems terms, they are the hubs connecting the two headquarters, coded with information that is not resident in the headquarters they are assigned to, and can thus bring the necessary variety to that headquarters to form the common image needed for joint

integration. In systems theory, the ideal liaison element would act as a superconnected hub, plugged equally into both systems, creating a source of attraction that fosters common internal images of environment and direction for adaptation in both organizations.

Underlying Dilemmas in Air Ground Operations

If irregular warfare is indeed inherently complex at the local level, then it follows that decentralization is needed to adaptively generate solutions suited to unique local conditions. This is in fact the approach that has been adopted to counter insurgency in both Iraq and Afghanistan. But there's a catch—operations have varying levels of scale (size of the effort in numbers of people, geographic span, moving parts, etc) in play simultaneously, and there are different levels of complexity in play at each level. Complexity must be defeated at the macro level — in this case, at operational level of warfare — to provide adequate predictability for large scale operations involving thousands of people. To provide that reliable supply and communication to support flexibility at micro levels, a hierarchical network, a bureaucracy, ensures reliable movement, care, and feeding of large but distributed organizations. To run a large, complicated bureaucracy, such as a combatant command, theater coalition, or joint force command, some kind of centralized control is required. Thus, you need to match the level of centralization to the level of complexity on different levels of scale, and realize that this will create tensions between those levels.

When Airmen argue for centralized control, they are recognizing this – it's tough to quickly configure for a major combat operation if you've distributed control and assets to subordinate commanders and have to go through administrative "foodfights" to recentralize when faced with a new large scale threat. With many decentralized efforts depending on the same centralized logistics, and given the realities of differing bilateral relationships among theater partners who don't necessarily

trust each other, the coordination and protection of critical logistics and lines of communication is usually best managed at the theater level.

This leads to the basic dilemma inherent in major military operations: you have to conduct both large scale operations and small scale operations at the same time, both depending on the success of each other, but there is no single organizational structure that is adequately suited to do both at the same time. Because of this, the military uses organizational hierarchies to address these problems:

> Most organizations, including the military, employ a hierarchy to separate problems at different scales. Lower echelons of the military hierarchy tend to have a shorter time scale, a faster battle rhythm, and a smaller area of interest. Higher echelons tend to focus on longer time scales, change more slowly, and focus on a much larger spatial scale, but with reduced resolution. This is a highly effective structure for solving problems that arise at different scales.[10]

While establishing hierarchies does help to mitigate these challenges, the dilemma of having to operate simultaneously at various levels of scale remains. One may establish different levels of hierarchy to deal with different levels of scale, but the different levels of both continue to be interdependent. Because operations at different levels of scale often require very different skill sets, coordination between these levels is a challenge, and it's not surprising when players focused on different levels of scale have trouble relating to one another.

Using Complex Systems Theory to Describe the Dilemmas

One need go no further than the current debates of effectiveness vs. efficiency between the ground and air components in our current conflicts to see how the ideas, concepts, and terminology of the new sciences could have an immediate positive effect. Without them, its almost impossible to understand and manage the tradeoffs between

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[10] Alex Ryan, "The Foundation for an Adaptive Approach: Insights from the Sciences of Complex Systems," *Australian Army Journal* VI (Summer 2009): 76-77.

various levels of scale and complexity in today's combat operations. Ground commanders conducting irregular warfare in places like Iraq and Afghanistan rightfully want more decentralized control at lower scale so they can deal with the fine tooth disorganized complexity in their area of operations, which often calls for different approaches from valley to valley. This creates a dilemma at higher levels of scale when their requests for air support often do not account for the requirements of adjacent AOs: the tendency in decentralized operations is to see one's own area of operations as a relatively closed system which is defined by specifically drawn AO boundaries, as well as the population within those borders, and the specific friendly forces and equipment organic to the unit assigned to the AO. Airmen tend to focus on the higher scale issues of organized complexity at the theater level as key to providing flexible support at those levels, but often fail to appreciate the need to sacrifice high scale efficiency for lower scale adaptability. With no one watching the "middle ground" between differing levels of scale, and few measures in place to estimate the risks to one by emphasizing the other, ground and air planners tend to talk past each other in "effectiveness vs. efficiency" debates, assuming that their level of scale is the yardstick by which the effort should be measured. In essence, members from both sides think they are arguing over the price of apples, not realizing that the other is talking about oranges.

This unintentional crosstalk only continues when the joint force commander or combatant commander fails to express his or her appreciation of the tradeoffs between levels of scale and complexity, and the levels of risk he or she is willing to take between the different levels of activity. This is not to say that commanders do not consider these tradeoffs intuitively, but rather that their ability to communicate these distinctions into guidance and mission type orders is currently hampered by a lack of common language to describe nonlinear concepts. When the

commander issues an apportionment decision in the linear terms of percentage of forces to each mission or line of operation, these multilayer tradeoffs are seldom expressed with enough distinction to show an appreciation for cross scale issues, let alone a determination which ones are the most pressing ones in a given situation. As long as linear concepts continue to predominate in our discussions of a nonlinear world, and the joint staffs who are supposed to arbitrate between them fail to step up to the task of managing between various levels of scale and complexity, the functional components will likely continue to talk past each other, fostering mistrust instead of true cooperation.

Cross Scale Disconnect: not just an Air Component Problem

The failure of the joint force to adequate address issues of cross scale coordination has become increasingly apparent in light of the increasingly decentralized nature of combat operations in places like Afghanistan, and is not just a challenge between functional components. When the ACCE was developed, it was intended to help alleviate the scale disconnects between the ground and air components, but it revealed a deeper problem inherent in complex combat operations. Even when the ACCE is trained and placed correctly, as it arguably was for Operation Anaconda, there is a fundamental aspect of decentralized planning that explains why the CFACC seldom gets advanced notice of significant increases in the amount of air support requested by the ground component: the ground component isn't aware of the total requirements until the last minute either. The various decentralized planning efforts of the various subordinate ground units are usually confined to distinct subdivisions of the ground commander's area of operations, and while these smaller unit actions are coordinated with adjacent small unit commanders, they are not coordinated among the entire ground component until only a few days before operations are set to commence, usually during a combined arms rehearsal briefing sometime between

96-48 hours prior to H Hour. This is typically when the ground component higher headquarters first sees the total combined effort of his or her various subordinate units, and is also the first time that the priorities for air support are submitted and prioritized in order to make the 48 hour prior deadline needed to get the air support request on the CAOC's air tasking order (ATO).

Why the MAGTF Model Can't Be Applied Universally

MAGTFs are specifically designed to have a predetermined allocation of air assets – and air liaisons—to support a specific ground commander, and as such, can enter the planning process knowing that they will have a certain minimum level of air support dedicated to them, anticipating further supplementation by CFACC missions as required and as available. This pattern cannot necessarily be applied to US Army operations in large operations because there may not be sufficient Air Force assets to provide a similar level of support for individual units like those provided organically in the MAGTF. While this may be possible in smaller scale contingencies, the number of distinct subordinate areas of operation in large ground operations may quickly exceed the number of air assets that can be assigned to them, requiring either sharing of assets or assignment to specific supported ground units at the expense of others.

Limited assets will usually drive a sub-apportionment of airpower between subordinate ground units. The current system embedding ALOs is very good at managing assets already in execution, but is not trained or manned to do the planning work of identifying the competing priorities for limited airpower within the ground component, and developing the logistics plan that supports the best possible mix of strike, airlift, ISR, and communications assets to support the ground component commander's overall scheme of maneuver. This can only be done at the

operational level, and necessitates the requirement for close coordination with the CAOC well in advance of execution.

The Emergence of Theater Level Air Support Requirements

A significant planning challenge for the air component is created when the sum of the individual ground efforts suddenly emerges as an aggregate theater level demand for air support assets. The overall priorities used to develop the logistics plan for air operations is typically issued 72 hours prior to execution in Air Operations Directive, which includes joint force commander's apportionment guidance, and puts the processes in motion that can be used to request and bed down additional air assets, determine the positioning of theater spanning air assets like carrier air, ISR, and tankers, and deconflict maintenance down days, plan surges, prioritize airlift support, etc. Putting all of these actions into motion usually takes more time than the 48 hour Joint Air Tasking Request system allows, meaning that urgent requests are dependent on the logistics plan that was determined and set in motion at the 72 hour point. While the air logistics plan can often still flex to accommodate the requirements of specific ground commanders, as it did in the case of Operation Medusa, it often results in the air component playing a "pick up game" when significant changes in air support requests emerge just prior to execution, just as they did in Operation Anaconda.

Air Force Liaison Before 2002

Until 2002, liaison between the Army and Air Force was provided exclusively by Air Liaison Officers, or ALOs, and enlisted Joint Tactical Air Controllers, known as JTACS. Graduates of the Air Ground Operations Course (AGOS), ALOS and JTACS are trained almost exclusively in tactical applications of kinetic airpower for close air support. Many ALOs are junior officers with no prior experience at the operational level of war. Often serving in their first assignment outside of the cockpit, many have little or no training in joint planning processes or

headquarters staffs. Thus, ALOs are usually only trained to operate at the tactical level of war, and seldom have sufficient rank, experience, or understanding s of joint air planning processes to offer holistic advice on airpower to ground commanders outside of close air support. Without having a grasp of operational level AOC processes and organizational concepts, they are not trained to recognize which elements of information are crucial to operational level airmen planning theater level air tasking orders. If they are assigned exclusively to one ground unit, they see only one piece of the air support puzzle, and will never provide early warning of a large aggregate demand for air support across the entire ground component.

The ACCE

While the ACCE was designed in 2002 to make up for this gap in liaison, it has still not provided the mechanism to close the gap between the air and ground components, which has contributed to the impression in many circles that the ACCE concept itself is flawed. The problems associated with the ACCE so far can be described as the results of "repair service behavior", the results of attempting a fix to problems of joint airpower integration without truly understanding the deeper scale vs. complexity problems that caused them. Complex Systems theories can give us a new lens with which to examine the underlying problem, propose what a liaison element should do, and then allow us to compare a theoretical liaison concept with the current ACCE concept in order to improve it.

Liaison According to Complex Systems Theory

If one looks at joint staffs as subsystems operating within the larger system of the joint force, a number of theoretical concepts can help us understand the role a good liaison element might play. Network theories are especially helpful in this regard. If one sees the air and ground components as two specialized networks, the liaison elements

can be seen as superconnected hubs that allow them to communicate, but still allow them to be separate enough to prevent the premature convergence that attenuates specialization and individual initiative. For any liaison element to serve as a superconnected hub, it should be highly connected to each larger system that it connects, and have sufficient structural knowledge of both to facilitate exchanges of variation needed for creative, dynamic adaptation. In practical terms, the liaison element should be constantly moving between sources of variation within the headquarters it its embedded in, but also must know which parts of the home headquarters can use or amplify that information. If the organizations are working at different levels of scale and complexity, the liaison should be able to facilitate the translation between them, which in essence requires competency in the logic and language of both sides in order to bridge high scale/low complexity operations and low scale/high complexity operations. This means that an effective military liaison must understand both the tactical and operational levels of warfare, and be able to translate the requirements of one into useful actions by the other.

In human systems, liaison elements need to be strategists of bureaucracy, facilitating both the high scale stability and high complexity that joint operations demand simultaneously, and helping the commanders understand the tradeoffs and risks involved in emphasizing either one. This combination of skills would be ideal according to principles of complex systems theory. The way they have actually been manned is a different story, and explains why the ACCE is often viewed with suspicion by members of both sides.

Why ACCEs Have Faltered

The way the Air Force currently selects, trains, and places members of the ACCE does not guarantee that the liaisons assigned have the experience they need to translate between different levels of scale and complexity in air and ground operations. There is no formal training

program for ACCE members, nor is there even a requirement for the completion of JPME I that would ensure basic familiarity with the full range of air component capabilities, The Joint Operations Planning Processes, and the structure and language of the component or joint headquarters they are embedded with. Airmen with little familiarity with AOC or supported component planning processes may be assigned to the ACCE without understanding how the organizations are supposed to work together in theory, let alone how they might adapt those theoretical constructs to the peculiarities of the nonstandard headquarters constructs that often emerge in joint and coalition warfare.

Without this bureaucratic expertise, the ACCE members may not be able to coordinate supported component requirements effectively to the CFACC staff at the CAOC. Even when ACCE members have this knowledge, additional challenges of location exist if they are not placed in the right locations, or are intentionally not allowed to circulate freely between the various ground component and joint shops and units to collect and share information.

Using Complex Systems Concepts to Fix the ACCE

If an ACCE was to be truly effective in serving as a super connected node and universal translator between levels of scale, its members should be able to do several things. They should first and foremost be experts of airpower, with both the tactical and operational expertise required to present ground commanders with holistic perspectives of how the complete inventory of airpower can be used either singly or in combination to support ground efforts, both in the kinetic and non-kinetic realms. They should also be able to speak proficient “groundspeak”, effectively serving as translators to hear what the ground commanders are asking for in their language, and relate the request for support in terms that the air component can understand. They should be able to direct requests for information from one

headquarters to the appropriate agencies in the other, and vice versa. They should be free to move about either headquarters, facilitating the kind of random encounters that increase awareness of issues that concern both components, and also build trust between the two headquarters that can only be created through personal interaction. And, perhaps most importantly, the liaisons have the aptitude, experience, and social skills needed to work the often thorny bureaucratic processes needed to translate between the requirements of different levels of scale and complexity between the components.

Whether or not one keeps the ACCE staff working directly for the CFACC as it is currently described, or places them under the ASOG, the same capabilities are needed to bridge the complexity to scale gap that currently exists when large scale air operations support decentralized ground efforts. An intermediate solution might be to help ALOs understand what information is critical to forward up to the operational level command and control elements by including command and control training in their certification, as well as a more comprehensive training program on holistic kinetic and nonkinetic airpower applications. While the focus of ALOs should remain mostly at the tactical level, concerned with providing direct support to the ground units with whom they are imbedded, the ACCE should be enlarged, and given more extensive training on operational terms and processes in both the ground and air operational headquarters. This would give them the ability to serve effectively as translators between components working at different levels of scale and complexity, and also push more planning and organizational expertise lower to support decentralized planning efforts in the ground component.

At the same time, the ACCE should maintain its independent status as a body of operational level experts not tied to a specific ground unit, but should rather be allowed to travel throughout that organization,

facilitating the random interactions that complexity theory tells us will lead to greater variety and improved communications between otherwise homogenous, locally biased organizations. An analogue can be made to patrolling white "hunter" blood cells in the immune system – their job is not to fight disease, but to sense it, bring information back to the bone marrow where specialized cells are made, and let specialized "killer" white blood cells do the job of actually fighting the disease.[11] This construct works because the seeker cell knows two things: how to identify the pathogen, and where in the system to go to generate a response. In other words, the white blood cell is programmed for both sides of the problem. The ones that patrol our bodies are not necessarily designed to be tacticians and fight specific pathogens—they're designed to be generalists, and call in the right specialized help exactly when and where it is needed. The same type of concept could be used for the ACCE, bringing in the right airpower expertise when and where it is needed, using mobility and focused response to mitigate the problem of not having enough Airmen or air assets to be everywhere at once.

Airpower Examined with Complex Systems Principles

If the networking concepts of complex systems theory can help us to improve our ability to act and adapt as a joint force, perhaps other applications can improve our ability to sense the environment, cope with emergent situations, and even profit from them.

Air Apportionment in terms of Exploitation vs. Exploration

Airpower has a unique ability to provide variety to the joint force due to it its unique ability to probe the enemy system without being limited by the constraints of terrestrial geography. Whether it is in trying to provoke an action by its very presence, covertly collecting information

[11] Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009), 181, 183, 285.

from ISR, or conducting active interdiction in areas where other forces are not present, airpower has a unique ability for exploration, which discovers previously unknown threats and opportunities. The recent trend is for airpower to be used primarily for exploitation, enhancing the joint force commander's ability to deal with already known threats and opportunities almost exclusively in areas where ground forces are already present. Commanders determining the apportionment of airpower between exploration and exploitation must understand the risks of each – while exploitation pays off immediately and can reduce costs in the near term, it limits the variety available for adaptation in the long term, increasing the risks of unpleasant surprise.

A practical application of balancing exploitation and exploration of airpower in our current irregular fights could be applied to better analyzing and understanding the tradeoffs between using airpower to directly support deployed ground forces vs. using them to probe and explore potential enemy sanctuaries and safe havens. If air assets are assigned purely exploitative roles, it will be impossible for the joint force commander to see new threats emerging, and by the time those threats move from their safe havens and engage the ground force, it may be too late for the joint force commander to request sufficient assets to handle that threat. Alternately, with at least some attention paid to exploration, the joint force commander has a better chance of detecting emergent enemy patterns of life, and may be able to act against them before the threats exceed the joint forces' current ability to respond within acceptable ranges of risk.

Improved Visual Decision Support and Assessment Tools

Despite the fact that airpower is inherently a nonlinear, multidimensional instrument, its effectiveness is often evaluated with linear measures that say little about the actual or potential value of airpower to commanders. Linear measures like labeling a mission only

as “close air support” when aircraft perform multiple missions on single flights are insufficient to tell the commander if the air component’s level of performance is acceptable, or even commensurate with the risks the joint force commander is willing to accept. Additionally, using two dimensional graphs to depict mutually supporting lines of operation may not show the benefits or risks in apportioning forces to one or the other. Multidimensional measures of performance and effectiveness can help us identify problems and risks on different levels of scale and complexity. Visual mapping techniques from complexity theory may help us to overcome false impressions of linearity, thus helping us form better understandings of the tradeoffs and risks of different courses of action.

Decision Support Tools

Instead of evaluating airpower with rich metrics, we usually fall back to things we can measure easily, and erroneously assume that they equate to effectiveness. Measuring the percentage of Joint Air Tasking Requests filled per day is one example of this. It is usually reported because it is easy to measure, and tells something about the air component’s ability to meet preplanned and emergent taskings, but says nothing about the potential customers that joint airpower could serve based on its preplanned or actual flight profile, and also has nothing to say about the actual effectiveness of the mission.

Advances in complexity theory can help us develop better measures of performance and effectiveness that help us identify problems and risks on different levels of scale and complexity. When we can better describe the possible second and third order effects of our actions on the system and the environment, we can better express the advantages and disadvantages between various courses of action in terms of tradeoffs in flexibility between levels of scale and complexity. For example, decisions about how far forward one decentralizes control of air assets could be expressed in terms of the advantages of increasing

local responsiveness to complexity, compared to the loss of responsiveness at the theater level, with the key risk considerations being the amount of slack one has in theater logistics, and the amount of risk one accepts in terms of responsiveness to emerging threats elsewhere in the theater. This risk might be expressed in terms of effective time to respond to an area denial attack against lines of communications, the loss of theater operations due to a theater ballistic missile attack, or the ability to conduct expeditionary operations to secure control of key chokepoints in the region not associated with current conflicts, which might make the continuation of those efforts untenable should a new conflict emerge.

The decision support methods we currently use to apportion and allocate airpower can also benefit from the tools of complex systems theory. Using two dimensional graphs to depict separate lines of operation may portray a false sense of separation of airpower effects – a bomber aircraft providing close air support can also provide ISR collection with its targeting pod, and also serves in a broader theater role as a deterrent to third party interference in irregular wars. Despite this multidimensionality, a single mission that provides all of these effects is usually credited only with providing one of them. Visual mapping techniques of both the system and the operation may help us to overcome false impressions of linearity, thus helping us form better understandings of the tradeoffs and risks of different courses of action. If the computer program used to generate the Master Air Attack Plan and the Air Tasking Order could also produce moving depictions of approximate routes of flight and area assignments, a time phased picture of the upcoming ATO could be used as part of the JFACC decision briefs. Further context of airpower effects provided by single missions could be displayed by a different colored radius of action circles for each capability that move with the aircraft depiction as the proposed mission is "flown"

on the computer, giving all commanders a much better sense of how much of the area of operations is being provided with airpower effects like presence, close air support response, and ISR coverage. Such a depiction would be a far superior way to demonstrate the air scheme of maneuver than a few Power Point slides, as it would show the emergent pattern of air activity.

If the separate functional components also had the capability to display their dynamic scheme of maneuver simultaneously overlaid with the other components', the entire joint force would have a much better picture of how successfully different assets from different services are supporting each other. For example, when considering how well the joint team provides air and missile defense, such a dynamic moving picture would show overlaps and gaps in air defense coverage as the various components execute their schemes of maneuver relative to each other, an especially important concept when the JFACC and JFMCC alternately support each other as air and naval assets move. Such a visual tool would not only graphically depict multiple levels of apportionment between different mission types and lines of operation, it would also provide a mission rehearsal capability that could identify seams in the joint plan, allowing the joint force commander to better synchronize joint forces.

If we could take a similar approach to execution, we could use networked capabilities to improve the situational awareness of both commanders in operations centers, and mission commanders over the battlefield. Datalinked information from each aircraft could be improved to link sensors throughout the force, to include information such as weapons configuration, sensor feeds, aircraft performance information, threat detection information, and aircrew biometrics. This information could be translated into rich inflight displays graphically depicting aircraft position and response times, fuel states, weapons status, and

surface unit being supported. Such displays would replace the two dimensional coordination measures currently done via two way voice and basic email communications.

Visual Tools for Assessment

While graphic collaborative tools would have great value for planning and execution, their greatest contribution may be to help us detect the aggregate patterns in the interactions of the joint force with regard to the enemy. One of the most difficult parts of assessing airpower's effects is to establish a linkage between actions in the air and reactions from the enemy. If we could use the same kind of multidimensional graphic tools that we use in mission rehearsal for operational assessment of actual missions flow, we could compare the air scheme of maneuver with the broader after action picture, and visually look for patterns and associations between air actions and enemy reactions. For instance, metrics are currently kept on hostile actions like improvised explosive devices, mortar attacks, and ambushes. Aircraft often fly over these same areas, both intentionally and randomly as the air tasking order is executed. Is there a correlation between aircraft overflight and reduced enemy activity in these areas? If we could graphically depict enemy actions superimposed on a replay of the actual air scheme of maneuver, recorded by sensors in the aircraft, tagged by time and location, we could compare the two to each other and visually look for relationships between the two. Such rich graphics can help us see the larger pattern of interaction between them both phased in time and space, just as moving weather maps do. Such advances have the potential to help us identify critical points of leverage that we can exploit with airpower, helping to create competitive advantages for the joint force.

Creating a Meta-Agent for Emergent Airpower Applications

Perhaps the most radical advance that complexity theory and advanced technologies could enable would be to allow us to simultaneously conduct a deliberate and emergent air scheme of maneuver – effectively blending the Western and Eastern theoretical traditions simultaneously. Airpower always takes off with a basic scheme of maneuver, which is described on the Air Tasking Order, but then assumes an emergent pattern as elements like weather, maintenance delays, mission changes, and emergency requests force missions to change from the preplanned profile. As aircraft respond to on call taskings, their flight paths become unpredictable. While their new mission destination may be determinate, their enroute flight path is often at the discretion of the aircrew, randomly taking them away from previously assigned taskings into areas of high and low interest for intelligence collection, on call close air support coverage, etc. If we use the principle of tagging to determine where these areas of high interest are, and make that information available to the operators and the automated computer programs on board, the aircraft can take advantage of their emergent flight path to gather pattern of life activity with their sensors as they respond to new taskings. If sensors for full motion video, signals intelligence, and even radar can be told where to look and what to look for as they fly along unanticipated areas, they can relay the information they collect, tagged by location and time, instantly to interested users who have been previously identified by digital tags. Available sensor time can also be advertised for emergent, realtime tasking to interested users, selected according to the controlling commander's priorities. This emergent activity may not even require conscious effort of the aircrews – with automated sensors and datalinked capabilities, sensors and radars can be controlled remotely when they are not needed by the aircrew members, who will always retain a manual override capability. This allows the same aircraft to prepare for weapons

release against a preplanned target, while also allowing collections of opportunity as the aircraft takes an unpredictable route to get there.

When adequate pattern recognition software is available, this process could be automated to facilitate continuous sensor use for mapping patterns of life, communications activities, and exploration into previously "untagged" areas where enemy activity may be emerging.[12] When memory and bandwith advances allow it, all sensor collections could be instantly relayed back to a networked database for storage, pattern analysis, and deliberate exploitation searchable by the time and location tags. This continuous interaction, which would take place simultaneously with deliberate tasks controlled by the aircrew, would in essence form an adaptive meta-agent that exploits the emergent activity of the air ground system. By combining all of these collections into a central database available for both real time and post mission analysis, these additional collections introduce new sources of variation into the system, and also facilitate institutional learning and adaptation as patterns of activity are identified are identified either by human or computer analysis of the data.

While future advances may give us better automated pattern recognition capabilities, the reality is that there is still no computer that can match the parallel processing capabilities of the human mind. The patterns collected by any meta-agent should still be primarily designed to

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[12] Charles Q. Choi, "Military to Adopt NFL's Instant Replay Technology," *LiveScience*, June 1, 2010,, HTML http://news.yahoo.com/s/livescience/militarytoadoptnflsinstantreplaytechnology;_ylt=AtqcpdrLOz8SKXxZJMydd9Cs0NUE;_ylu=X3oDMTRvM2UwdmVmBGFzc2V0A2xpdmVzY2llbmNlLzIwMTAwNjAyL21pbGl0YXJ5dG9hZG9wdG5mbHNpbnN0YW50cmVwbGF5dGVjaG5vbG9neQRjY29kZQNtb3N0cG9wdWxhcgRjcG9zAzEwBHBvcwM3BHB0A2hvbWVfY29rZQRzZWMDeW5faGVhZGxpbmVfbGlzdARzbGsDbWlsaXRhcnl0b2Fk/ (accessed June 1, 2010).

stimulate the man or woman in the loop, who can identify if the detected patterns of activity have meaning within the larger context of the conflict.

At the same time, we must guard against the pitfalls of the human mind which tend to resist change. Creating a meta-agent for ISR that collects only through emergent opportunity, and requires no deliberate tasking or post mission analysis unless a tagged pattern recognition threshold is reached, runs counter to the current bureaucratic processes used by the ISR community, and also is not intuitive for aircrews who are used to deliberate taskings and debriefs. To truly exorcise the most possible latent capability of airpower, the humans in the system will have to become more comfortable with ways of planning and thinking that run counter to the current linear concepts like prioritized ISR collection lists of preplanned flight routes. The real benefit of the meta-agent will not be in providing *more* information on the things we already know something about, but rather in providing the *first* indications of something we should know *something* about.

Takeaways for Airmen

The language and tools of complex systems theory have the potential to radically transform the way we employ airpower, even if they only help us better understand the simultaneous effects that airpower has always created. The speed and range of airpower makes almost any air operation a complex one, and adding a third dimension of maneuver alone exponentially increases the number of variables that must be considered if one is to contemplate the emergent phenomenon we describe as airpower, a phenomenon that only exists in reality when the pieces of the air system are moving dynamically, even if the mere potential for this movement is enough to influence other systems. Perhaps the question isn't whether or not we apply complex systems concepts to airpower or not, but rather "How did we get this far without them?"

The debates about the proper mix of efficiency vs. effectiveness of airpower supporting ground operations have brought a bigger problem in the joint force into focus: our lack of understanding of the fundamental tradeoffs between various levels of scale and complexity. The requirement to manage the complicated nature of modern warfare led to the emergence of the operational level of war and the bureaucratic staff processes commonly identified with them, but our understanding of why they were necessary has been incomplete without the insights of complex systems theory. Overall, the joint force has become extremely effective and efficient at the tactical level of warfare, and increasingly better in designing operational level organizations and concepts, but our ability to bridge the two levels has been lacking. Airmen have brought this issue to the forefront because they constantly operate on the edge between levels of scale, and often operate in both simultaneously as the same aircraft performing direct support missions for irregular warfare can serve as a deterrent to major combat operations elsewhere in the theater. As we use complex systems concepts to understand the tradeoffs in competing priorities for air support, we should gain insights that have broader application to military strategy in general.

The technology that has helped us detect emergent patterns in complex systems also can help us understand emergent patterns in warfare, and provide us multidimensional decision support and assessment tools that give us the same flashes of insight that our moving weather map does. Just as lighting strikes can be recorded, tagged, displayed automatically in realtime, and cataloged historically to be shown along with weather trends, so too might we someday be able to unconsciously collect and compile indicators of enemy activity as we happen to fly over the battlefield while we're doing something else. Ultimately, it's the human brain that analyzes patterns of weather activity and puts the various pieces together to decide if the weather is a

blessing or a curse. So too must we translate collections of emergent intelligence into products that humans can use to interpret emergent activity, predict their future trends, and evaluate whether action should be taken in response to them.

Conclusion

Given these insights from complexity and systems theories, what are the main takeaways for the military strategist, and more specifically, for Airmen? If we're to understand the living and nonliving systems that define the operational environment, we must adapt conceptual models that mirror the world as accurately as possible, and then match organizational designs that are compatible with that reality on various levels of scale. Unfortunately, our current models for assessing the operational environment and conducting operational art are lacking in this regard.

We don't have the luxury of solving for one problem at a time (i.e. security, reconstruction, fighting corruption, illegal drugs, maintaining domestic support and campaign authority, deterring external aggression, etc). Short of time travel, time is the one constant that always works against us in dealing with complexity. We can design new tools to help us understand what other tools are doing to us and the environment, but we're ultimately limited by the time it takes the neurons in our brain to detect, process, and store information. Despite the basic cognitive limitations of the human being, machines have not yet been able to replicate the ability of the human brain to perform the simultaneous parallel computations required to relate and cross index seemingly unrelated pieces of data to one another. The basic underpinning of human humor is the ability to relate disparate things in a way that goes against logic, a paradoxical computation that no computer can yet duplicate.

If an organization is to survive, compete, and flourish in a complex, adaptive world made up of other living systems, it must emulate this ability to conduct parallel processing between people and

suborganizations. We need to find ways to design both organizational structures and processes of interaction that promote successful adaptation and learning.

In its essence, strategy is all about using your understandings of the causal relationships between living and nonliving elements of the operational environment to “place bets” about what possible choices will increase desirable outcomes while mitigating negative ones within a range of acceptable risks.[1] To do this, one must have some kind of understanding about the current state of the environment, one’s potential ability to influence an adaptive system over time, and also how other living and nonliving elements of the environment will influence, be influenced by, or react to our actions. Since time never stops, and never goes backward in our current paradigm, one has two basic choices: 1) Do nothing and see what happens; 2) Do something and see what happens. Either way, to be proactive one must first model the system mentally and simulate future outcomes, then update the mental model based on observations about what is actually happening. The better we can build and adapt these conceptual models, the better our chances of choosing combinations that push the system in the direction of our desired outcomes, even if we can never guarantee them.

If there is a noticeable level of cognitive dissonance inherent in the joint planning processes, it is perhaps because we have merged linear and nonlinear thinking and attempted to put two completely different views of the world together under the same tent of joint doctrine. We take prescriptive, linear Jominian concepts such as decisive points and lines of operation that presume that the world can be adequately approximated with linear concepts, but also accept the descriptive

[1] Dr. James Forsyth, "Class discussions," speech delivered to School of Advanced Air and Space Studies seminar, August, 2009, Air University, Maxwell AFB, AL.

Clausewitizan concepts that war is defined by moral forces like passion, chance, and reason. So which side is right? They both are, but both are incomplete, and stem from different starting assumptions. More accurately put, one approach is less wrong than the other when one matches the right approach to the situation based upon the relative complexity and scale of the situation.

Our current linear based concepts like center of gravity analysis are not unlike Aristotle's division of the natural word into four elements—it's more useful than calling everything the same, but gives little context to help us cope with the complex operational environment that nearly every current assessment acknowledges. It is only in recent history that we defined three levels of war, with the inclusion of the operational level of war between the historically acknowledged strategic and tactical levels. Did not having this definition prevent us from fighting wars before we had such intellectual constructs? Of course not. The operational level of war has always existed whether we defined it as such or not. But the increasing complexity of war at different levels of scale drove us to find new terns and concepts to deal with the mental discomfort from higher complexity due to factors like industrialization, digitalization, and national mobilizations for war.

Recent explorations into the term "hybrid warfare" compared with Major Combat Operations and Irregular Warfare have highlighted our difficult in seeing both the pieces and the whole at the same time. On one side of the argument, resistance to the new term reminds us that "War is war," rightfully insisting that the underlying logic of war, that is, the logic of human politics and interaction, does not change in its essence despite advances in technology and learning. On the other side, our recent experiences in Iraq and Afghanistan have provided costly reminders that having a capability for one mode of warfare—major combat operations—does not guarantee capability for other modes like

irregular warfare. Which side is right? They both are—each describes part of the holistic reality of war, just from different intellectual starting points. The key to successful adaptation in war is not to label war as regular, irregular, or hybrid. Rather, the key is to identify commonalities with historical patterns that enable prediction, recognize key differences that separate the current reality from past experience, and attempt to solve for both at the same time. Neither nonlinear nor linear thinking alone is sufficient to give us this ability—we must use insights from both perspectives to define and attack complex problems.

The reality we must come to grips with is that linear thinking is good for describing pieces of the world, but inadequate to comprehend the whole. Clausewitzian center of gravity analysis is good as a process to break up a complex world into more manageable descriptions of our most pressing threats, but it is folly to assume that one could approximate a multidimensional world moving forward in time by focusing one's actions primarily on one center of gravity on three levels of war. Clausewitz himself is perhaps best known for saying that "The first, the supreme, the most far reaching act of judgment that the statesman and commander have to make is to establish by that test the kind of war on which they are embarking; neither mistaking it for, nor trying to turn it into, something that is alien to its nature."[2] We cannot hope to understand the nature of any war without conceptual models that reflect the world as it is, not the "one COG per level of war" model that we might be more comfortable with. If the world truly is becoming more complex, we need something more responsive and dynamic as our cognitive model on which to base our predictions and assessments of how we can influence that world.

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[2] Carl Von Clausewitz, *On War*, trans. Michael Howard and Peter Paret (Princeton: Princeton University Press, 1984), 88.

In the wake of USJFCOM's revocation of EBO, Lt Gen Van Riper wrote a thorough critique of it supported with justifications derived from complex systems theory.[3] While his critique was indeed sound overall, and demonstrated a clear grasp of the concepts of complex systems theory that joint EBO did not, his assertion that "there was no baby in the bathwater" was perhaps an overreach. The USJFCOM commander was indeed correct to put a stop to what had become an unworkable mess of linear and nonlinear concepts, but the core concept behind EBO remains sound: we should seek understand ourselves, the enemy, and the environment as a system, and then attempt to balance multiple problems as close as possible to the level their sources, not at the level of their symptoms. This way of thinking, the antithesis of "repair service" behavior, is entirely appropriate in a world of complex systems, but must be extended to include the nonlinear aspects of the operational environment as well, even if it can never be done with absolute certainty.

If for no other reason, Airmen must embrace complex systems concepts in order to participate constructively in meaningful discussions about war and operational art with our sister services. But once they do, they will find a language that is specifically applicable to their domain. If there is one thing that most distinguishes airpower from the other combined arms, it is the ability of airpower to overcome linear limitations associated with operating on and under the surface. The multidimensionality of airpower is nothing new to Airmen – the intellectual concepts and terminology of complex systems theory can give Airmen a new capability to share these capabilities with the other services in the context of joint warfare. It also will allow them to do it in a language that the other services are increasingly familiar with as they

[3] Paul Van Riper, Lt Gen (ret), USMC, "EBO: There Was No Baby in the Bathwater," *Joint Force Quarterly*, no. 52 (First Quarter 2009).

grapple both physically and intellectually with the nonlinear elements of our current irregular warfare fights.

In the larger sense, good strategy is perhaps less about finding specific solutions than it is about balancing competing positive and negative goals simultaneously and continuously. Often short term exigencies must take priority, but even in these cases, a good strategist must at least recognize that immediate solutions often create an entirely new problem that will have to be dealt with in the future – we're constantly mortgaging future time and interests to pay for efficacy in the present. It's the strategist's role to actively use all of the tools available to express these opportunity costs as potential risk, and to guard against short term solutions that ultimately prove to be little more than Pyrrhic victories. Only a multidimensional analysis can hope to provide the insights we need to tackle all of these problems simultaneously.

In seeking greater clarity about the nature of the world, we would be foolish not to adopt the same complexity based approaches that others are using successfully in other disciplines such as business, science, and medicine. Our efforts to see the world through the lenses of complexity and systems may be a difficult adjustment at first, but we can also look to them to reassure ourselves that we are more than capable of adapting to new paradigms, just as we always have.

> Sooner or later a new simplifying conception is discovered that cuts at the root idea behind the old system and replaces it. Copernicus's dazzlingly simple astronomical system, based on a heliocentric universe, replaced the hopelessly complicated Ptolemaic system. Whittle's jet engine, ironically, replaced the incurably complicated piston aeroengine of the 1930s before it also became complex. And so growing complexity is often followed by renewed simplicity in a slow back-and-forth dance, with complication usually gaining a net edge over time.[4]

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[4] W. Brian Arthur, "Why Do Things Become More Complex?" *Scientific American* 5, no. 268 (May 1993): 144.

The sooner we make the transition to the language and concepts of the new sciences, the better equipped we will be to see the world as it really is, have a better understanding of how military power relates to other elements of national power, and the less complex our current fights will seem to be. The more precisely we can describe the world, our problems, and our plans to create solutions, the more likely we are to ask the right questions, solve for the right problems, and do more good than harm in a complex, adaptive world. Even if these concepts of complexity are only a stepping stone towards something more precise, they're they next step that we must take in our effort to understand both war and strategy. Once we do, it's likely that our children will someday look back at us the way we look at Aristotle today, and the way he must have once looked at the proponents of Thales, wondering, "Did they really think that the world was that simple way back then?"

Annex A

Using Visual Thinking Principles to Write This Thesis

Immersing oneself in the various works of an emerging science is a complex challenge in itself. As I confronted my goal for this thesis, which was in essence to write a primer on complex systems for Airmen, I quickly realized that conventional methods of sequential paragraph writing and piecemeal turn-in of chapters to my advisor did not suit my complex task. Thinking that I could test my subject with my investigation, I chose to write this thesis using the principles of visual thinking.

My task was complex because I had to go through various works on complexity and systems theories, from the background of various disciplines, and reconcile various ideas that were similar but not the same. I initially tried to do this in Microsoft Word with a two dimensional traditional outline, but quickly found that due to the constraints of text size and limited monitor space available, I could not make sufficient mental associations between numerous sources of information, even with the search function of the word processor. I had to find a better way to get my mind around the problem, and the linear tools on my computer were not sufficient for the task. I then decided to try out some of the concepts I was studying, and apply visual concepts to writing my thesis.

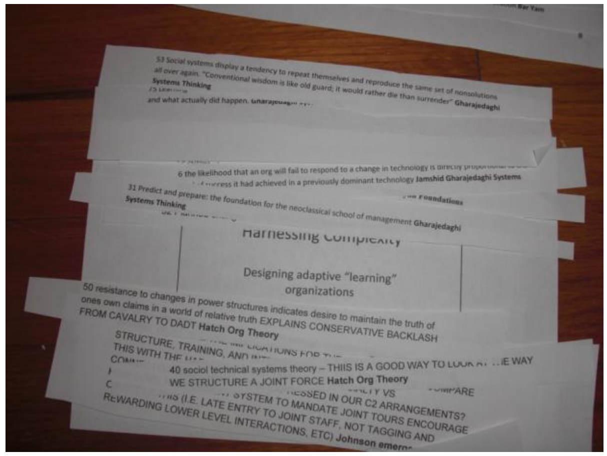
My initial method of research had been to take notes on my computer as I was reading, so I had a printable list of supporting information tagged by source. But each work covered multiple topics from different directions, and my paper would be lacking in healthy

variety if I depended on only one source per topic. What was the best way to remember what I had read, and to separate the different approaches to complexity? My answer was to create a visual model of my research - and a visual model of my thesis in progress – on the floors of my house.

By laying out the primary sources next to each other rather than stacked on a bookshelf, the book covers became tags which allowed me to quickly identify the location of the book, and books with similar concepts could be place in proximity to one another. By a quick visual scan, I could instantly review the mental tags in my mind which represented the thesis as a whole, based on the general ideas that each book presents. I now had a model of what I had read which I could access visually and simultaneously, vastly outstripping my capacity to juggle the various sources through mental recall alone.

My next use of visual thinking was to place proposed paragraph topic sentences on large squares, and group them in relation to one another by concept. The central vertical groupings represented the core ideas of the thesis, while the supporting ideas for those were depicted horizontally, with further support of those stacked vertically under them. Upon these squares, I placed smaller strips of paper with the key concepts from my notes, tagged with the source and page number, and

cut into hundreds of separate quotes. By doing this, I was tagging each reference with an association to its main idea.

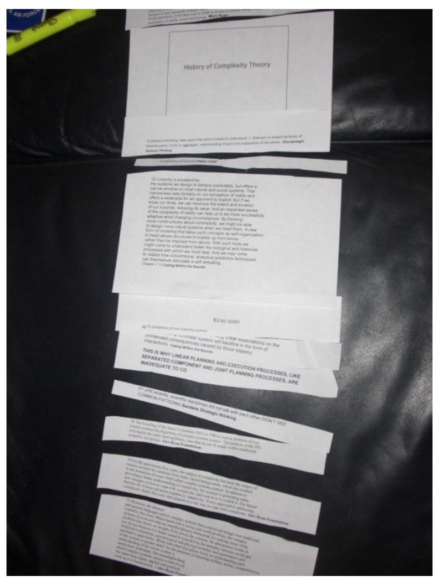


As I worked through the different main ideas as possible paragraph headings, I looked at their relationships to one another, and started to form relationships and the logical sequences between them, which I expressed visually by creating a more ordered hierarchy of paragraphs.

The actions of laying out the large topic squares and the smaller supporting two actions forced me to do several things in my mind that simply working on a word processor would not have facilitated. I first

had to form associations between the main ideas of the paper in relation to one another. As I placed the squares, I thought about the concepts, and their relationships to one another. Throughout the course of my research, if I had a flash of insight about their relationships, I moved the squares around until the visual model matched the association I had made in my head. By having the capability to look at various parts of the thesis simultaneously, I was effectively seeing the thesis as it emerged in my own mind, helping me control the flow of my own insights before the writing process even started. This also forced me to reflect both with the conscious and subconscious mind as both mentally and physically interacted with the model.

While having to place hundreds of cut out supporting quotes was somewhat tedious, it forced me to look at each piece of information in the context of the whole project, and reinforced the specific insights with the greater concepts on the large squares. It also gave me a visual depiction of the variety I had in the thesis by subject, and allowed me to almost instantly canvas my entire body of research for alternate sources to support similar points. I could also lay different supporting ideas one on top of the other to help determine the order of concepts in the individual paragraph. The final layout became the outline I referenced while writing the paper.



The reader can judge the relative effectiveness of the results, but from the researcher's standpoint, the visual model was an invaluable, albeit technologically unsophisticated method to engage with a complex subject.

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